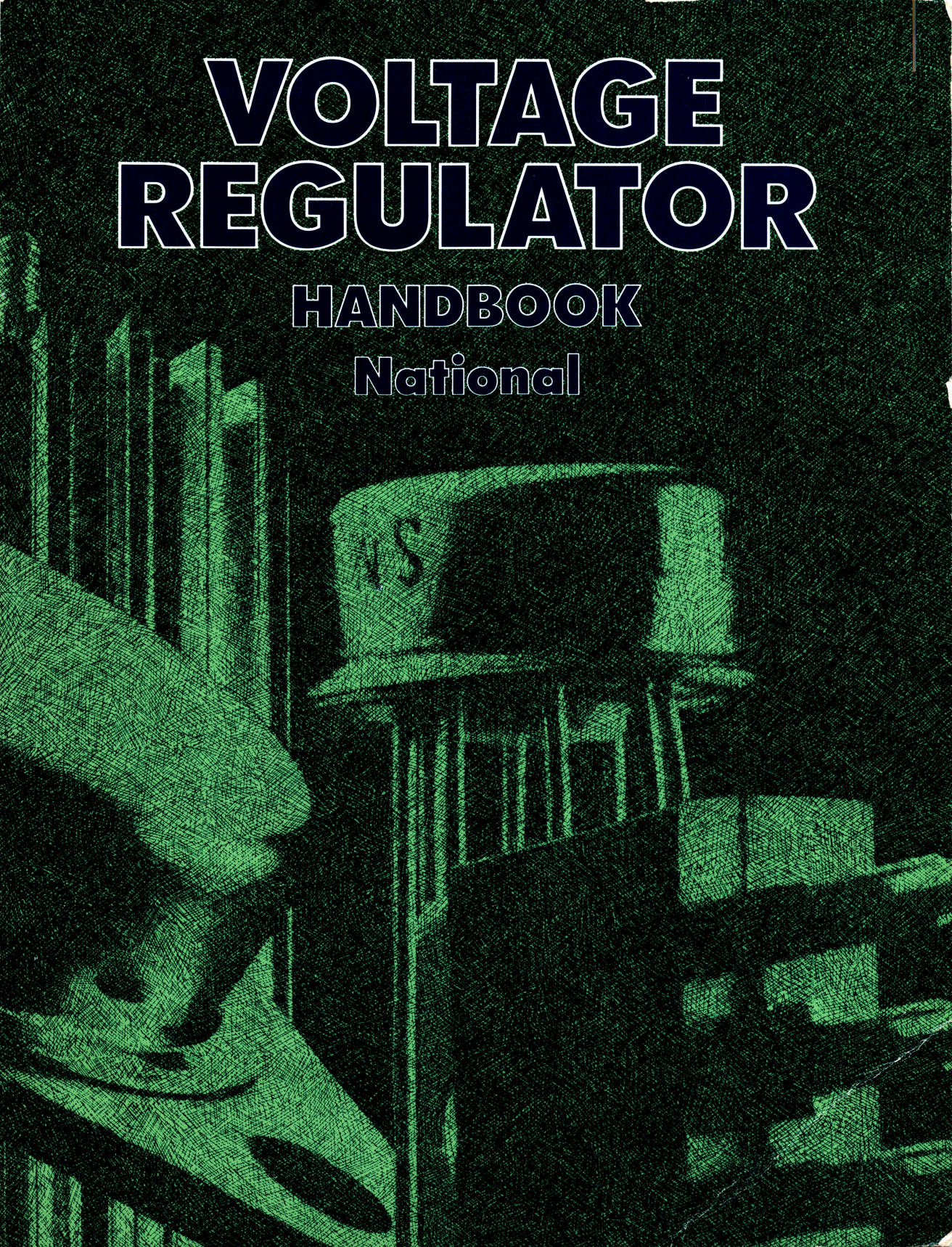


VOLTAGE REGULATOR

HANDBOOK

National





VOLTAGE REGULATOR HANDBOOK

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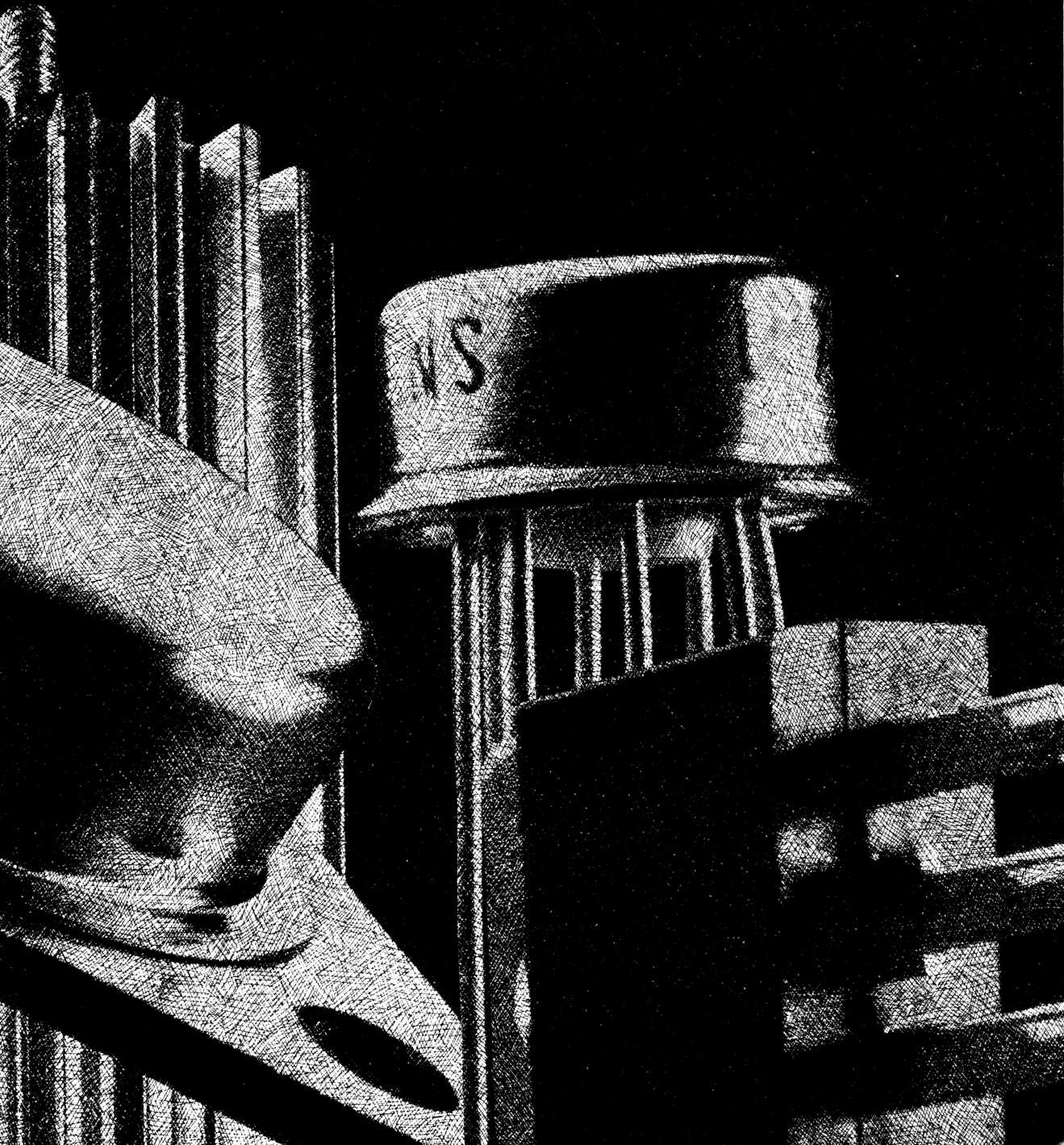
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Section 1.0

Introduction





1.0 INTRODUCTION

1.1 HOW TO USE THIS BOOK

This manual has been created and arranged to simplify the task of selecting an appropriate three-terminal regulator according to your specific system needs. Information is also supplied on heat sink selection and design, power transformer and filter specification, and on various extended use applications for the basic three-terminal and dual tracking regulators.

If a system supply already exists and regulation is required at a current range or voltage listed in Figure 1.2, selection is relatively easy. Make initial selection from Figure 1.2 and the data sheet summary in Section 2, then go directly to the product selection procedures of Section 3.

If a higher current is required, refer also to Section 7, Applications, for current booster circuits.

Where a heat sink is required (possible with K, S, T & P suffix devices), refer to Sections 5 and 6 on heat sink selection and design.

For small systems using only one regulator or if a system supply does not yet exist, Section 8, Power Supply Design, provides the information necessary to specify transformer output voltage and current, diode characteristics, and filter capacitance.

For applications other than simple three-terminal regulation (listed in Section 1.3), refer to Section 7, Applications.

For voltage regulation at other than the voltages listed in Figure 1.2, refer to the applications section, or consider an adjustable regulator such as the LM105, LM723, etc. Refer to the data sheets on these parts and to the National Semiconductor Linear Applications Handbook. Section 1.4 compares the features and applications of three-terminal and adjustable regulators.

Ordering information is covered in Appendix 2.

Test methods and circuits are covered in Appendix 4.

A cross-reference listing the National Semiconductor part number most closely matching other manufacturers' part numbers is in Appendix 6.

1.2 FEATURES OF ON-CARD REGULATION

The trend in voltage regulation is toward localized regulation with smaller, low-cost, low-current, fixed-voltage IC regulators which require minimal or no heat sinking and few or no external components. In the past, one used bulky, high power regulators or regulators made up of many discrete components to regulate a line which supplied all areas of an electronic system. Unfortunately, the impedance of this line and associated connectors caused voltage drops which varied throughout the system. Also, any common impedance in the line between chassis or cards could allow unwanted coupling between critical parts of the system. These older systems often required considerable bypassing or decoupling which caused degraded local regulation. More recently, simple three-terminal regulators supplying one to three amps have been placed on individual cards within a system. These, however, are often larger in capacity and price than is necessary for one-per-card use. If used to supply several cards and fully loaded, some of the same old problems recur. The newest regulator designs emphasize low-current ranges and small, low-power, three-lead packages. These regulators are available in a variety of positive and negative voltages at current ranges of 100 mA to 3 A, some in packages as small as the TO-92 plastic small-signal transistor. There are also dual tracking ± 100 mA regulators in TO-100 or plastic power DIP packages. With this variety to choose from, it is now possible to select the regulator for each application, and reduce cost significantly over competing approaches.

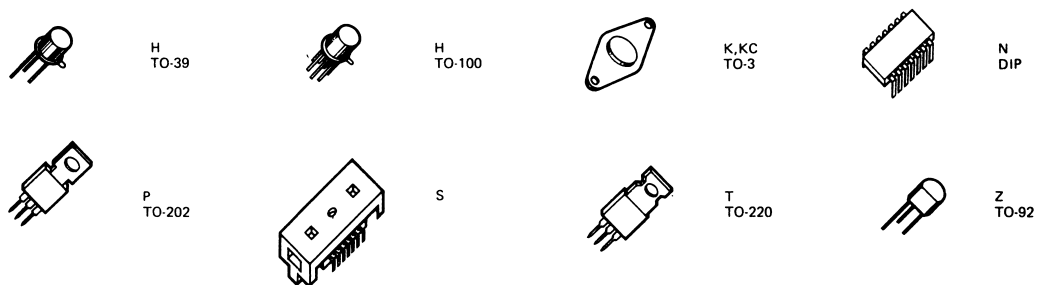


FIGURE 1.2. Available Regulator Packages

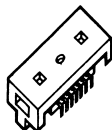
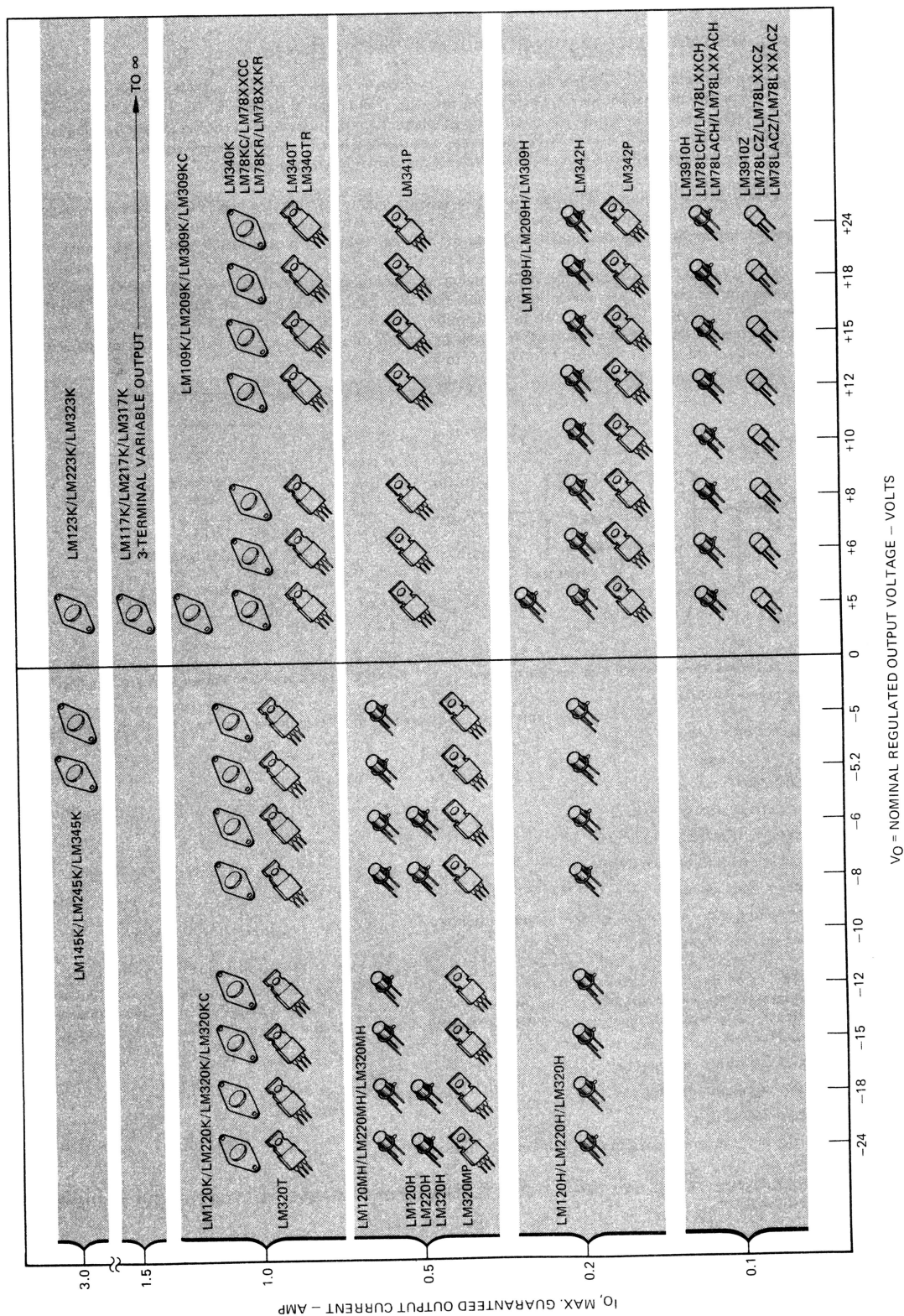
	$\pm 15\text{ V}$	$\pm 12\text{ V}$	$+5\text{ V}/-12\text{ V}$
	LM125H, LM225H LM325H	LM126H LM226H LM326H	LM127H LM227H LM327H
	LM325N	LM326N	LM327H
	LM325S	LM326S	LM327S

FIGURE 1.2a. Dual Tracking Regulator Package Selection Guide



1.3 FIXED VOLTAGE THREE-TERMINAL REGULATOR DESCRIPTION

A graphic comparison of the available regulators and packages is made in Figure 1.2. All include short-circuit protection, automatic thermal shutdown, on-chip pass transistors, and internal references. The LM125-127 series are dual tracking regulators with provision for external boost while using the internal circuitry for current limiting in the boosted mode (Figure 1.1b). The LM125-127 series are essentially a pair of three-terminal regulators, one positive and one negative, while the others are single three-terminal positive or negative regulators.

With the exceptions to be noted, all listed regulators operate simply without the need for external components. Normal connections are as indicated in Figure 1.1. If the regulator is located more than two inches from the supply filter capacitor, a supply bypass capacitor is required to maintain stability (much as is the case with op-amps). This should be an $0.22\ \mu\text{F}$ ceramic disc, $2\ \mu\text{F}$ or larger solid tantalum, or $25\ \mu\text{F}$ or larger aluminum electrolytic capacitor (the LM120 and LM123 series require the solid tantalum or aluminum electrolytics). The LM120 series alone of all the group requires an output capacitor to insure stable operation. This should be a $1\ \mu\text{F}$ solid tantalum or $25\ \mu\text{F}$ or larger aluminum electrolytic capacitor. With this exception, no output capacitor is required for stability; however, transient response and noise rejection can be improved by adding an output capacitor. An $0.1\ \mu\text{F}$ output capacitor is recommended for the LM78LXX and LM3910 series to minimize high-frequency noise.

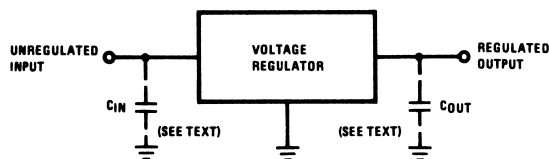


FIGURE 1.1a. Normal Three-Terminal Regulator Connection

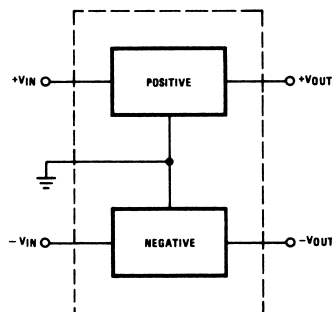


FIGURE 1.1b. Basic Fixed Voltage Dual Tracking Regulator

In addition to their normal fixed-voltage application, the three-terminal regulators may be used in the following circuits (discussed in Section 7):

- Current regulator
- Adjustable voltage regulator
- High current boosted regulator
- High current switching regulator
- Regulator with electronic shutdown
- High voltage regulator
- Combined + and - regulators for dual balanced supplies
- Tracking dual regulators

The LM125-127 series dual tracking regulators are unique in that they are the only available tracking regulators which incorporate thermal shutdown, require *no external components in normal operation*, and allow addition of external boost using few additional components. Special applications for the tracking regulators are discussed in Section 7, as follows:

- High current boosted operation
- Foldback current limiting
- Electronic shutdown
- Positive current dependent simultaneous current limiting

1.4 COMPARISON, FIXED VOLTAGE THREE-TERMINAL vs VARIABLE VOLTAGE REGULATORS BY APPLICATION

A simple comparison between three-terminal regulators and variable regulators (e.g., LM105, LM723, etc.) appears in Table 1.1. The variable regulators are most useful for providing non-standard voltages, switching regulators, or in programmable-voltage high current supplies with foldback current-limiting.

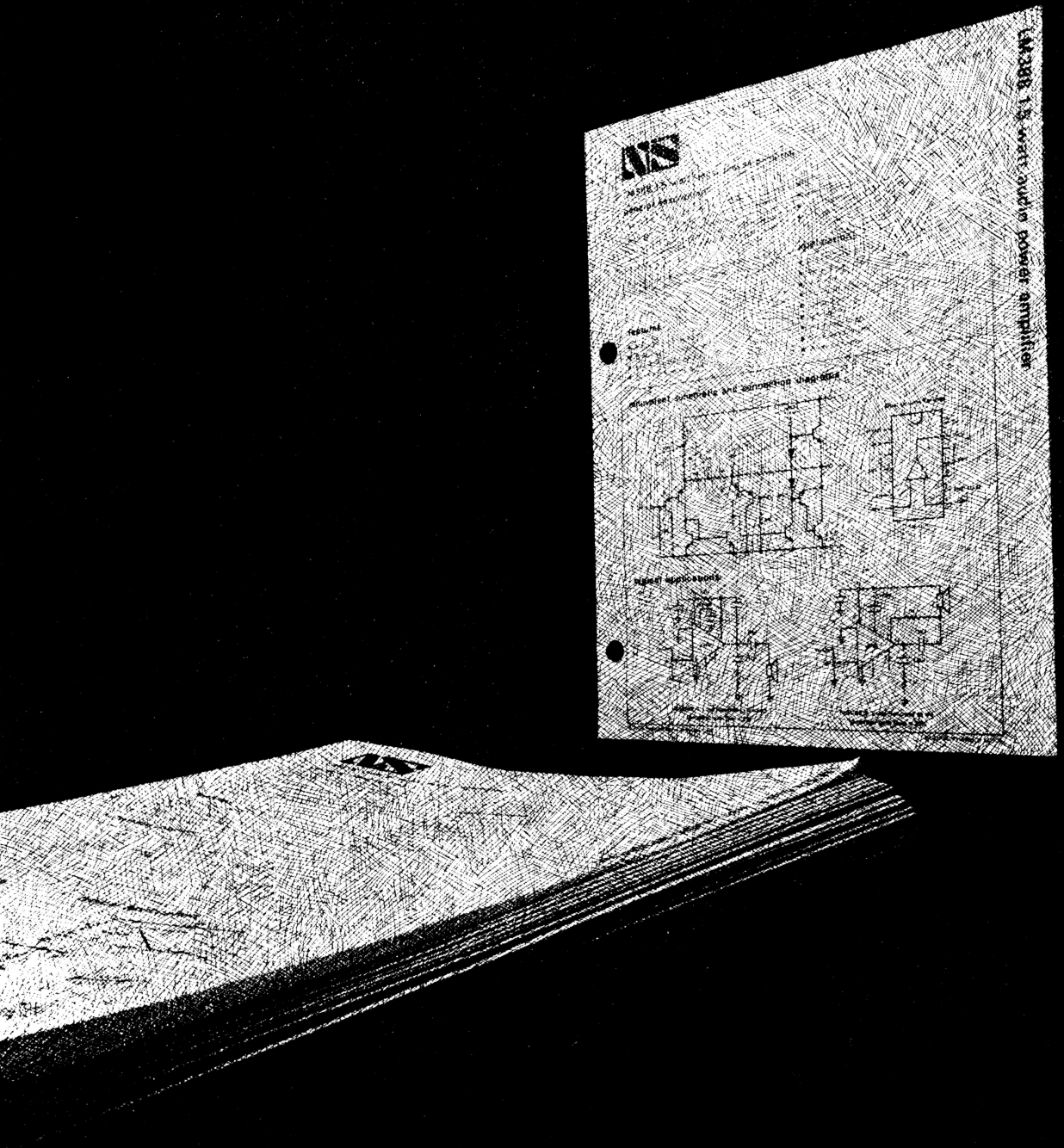
Table 1.1 Comparison of Fixed Voltage Three-Terminal Regulators and Variable Regulators by Use or Feature

USE/FEATURE	FIXED OUTPUT VOLTAGE	VARIABLE OUTPUT VOLTAGE
Features: - Current limit - Thermal shutdown - Voltage reference noise bypass - Electronic shutdown - Programmable output voltage	- Internal - Internal - Not possible, but noise is comparable to bypassed variable reg. - Fairly complex external circuit - Practical with some performance loss	- Practical with external circuit - Complex external circuit - Single capacitor - Simple external circuit - Simple and effective with two resistors
Uses: - High output voltage - Current regulator - Switching regulator - Current boost - Foldback current limiting	- Fairly complex circuitry - Practical - Self-oscillating mode. No short circuit protection on switching transistor - Possible (easy with LM125-127) - Internal (not programmable) for all three-terminal regulators. - Programmable for LM125-127.	- Simple external circuit - Practical - Self-oscillating or driven modes. Short circuit protection, but must be added for external pass transistor - Practical - Requires 2 resistors (pos. only), more complex for negative

Table 1. Comparison of Fixed Variable Cost Formulas and Variable Cost Formulas

Variable Cost Formulas	Fixed Cost Formulas	Total Cost Formulas
Variable cost per unit = Total variable cost / Total units produced Variable cost per unit = Total variable cost / Total units sold Variable cost per unit = Total variable cost / Total units available for sale Variable cost per unit = Total variable cost / Total units in inventory Variable cost per unit = Total variable cost / Total units in production	Fixed cost per unit = Total fixed cost / Total units produced Fixed cost per unit = Total fixed cost / Total units sold Fixed cost per unit = Total fixed cost / Total units available for sale Fixed cost per unit = Total fixed cost / Total units in inventory Fixed cost per unit = Total fixed cost / Total units in production	Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit
Variable cost per unit = Total variable cost / Total units produced Variable cost per unit = Total variable cost / Total units sold Variable cost per unit = Total variable cost / Total units available for sale Variable cost per unit = Total variable cost / Total units in inventory Variable cost per unit = Total variable cost / Total units in production	Fixed cost per unit = Total fixed cost / Total units produced Fixed cost per unit = Total fixed cost / Total units sold Fixed cost per unit = Total fixed cost / Total units available for sale Fixed cost per unit = Total fixed cost / Total units in inventory Fixed cost per unit = Total fixed cost / Total units in production	Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit Total cost per unit = Variable cost per unit + Fixed cost per unit

Section 2.0 Data Sheet Summary



2.0 DATA SHEET SUMMARY

Table 2.1 lists the various regulators and the most useful specifications for each. Note that accuracy specifications are over the full temperature range including drift. Room temperature accuracy specifications are about 1% better than the figures given.

TABLE 2.1. Data Sheet Summary

POSITIVE VOLTAGE REGULATORS												
DEVICE ^{1,2}	V _{OUT} over temp range (V)	(±%)	Regulation Line ³ Load ⁴ (mV/V) ⁵	Max V _{IN} (V)	Max I _Q (mA)	Typ Ripple (dB) ⁶	Typ Dropout Voltage (V)	DEVICE	Pkg Style	Rated I _{OUT} (A)	Typ θ_{JC} (°C/W)	Typ Max θ_{JA} P _D (°C/W) (W)
LM109, LM209 LM309	5	8 5	10 10	20 20	35 10		1-2	LM109H series LM109K series	TO-39 TO-3	0.2 1	15 3	150 35 2
LM123K, LM223K LM323K	5	8 5	5	20	20	20	1.7-2	LM123K series	TO-3	3	2	35 30
LM340	5, 6, 8, 12, 15, 18 24	5 ⁷	20	20	35 40	10	74	LM340K LM340T	TO-3 TO-220	1 1	4 4	35 50 18
LM341P	5, 6, 8, 12, 15, 18 24	5	20	20	35 40	10	74	LM341P	TO-202	0.5	12	80 12
LM342	5, 6, 8 10, 12, 15, 18 24	5	20	20	30 35 40	6	74	LM342H LM342P	TO-39 TO-202	0.2 0.2	40 12	140 80 10
LM78LXXAC	5 8, 12, 15, 18 24	5 ⁸	20	10	30 35 40	6	74	LM78LXXACH LM78LXXACZ	TO-39 TO-92	0.1 0.1	40 40	140 180 1
LM3910	5, 6, 8, 10 12, 15, 18, 24	3			40	4	1.5-2	LM3910H LM3910Z	TO-39 TO-92	0.1 0.1	40	140 180 1
NEGATIVE VOLTAGE REGULATORS												
LM120, LM220, LM320	5, 5.2, 6, 9, 8 ⁹ 12, 15, 18 ⁹ 24 ⁹	5	10	20	25 35 ¹⁰ 40	4	2	LM120H series LM120K series LM120T series	TO-39 TO-3 TO-220	0.2 1 ¹¹ 1 ¹¹	15 3 5	150 35 50 2
LM145, LM245, LM345	5, 5.2	4	5	20	20	3	2	LM145K series	TO-3	3	2	35 25
DUAL TRACKING REGULATORS												
LM125, LM225, LM325	±15	5	1	1	30			LM125, 126, 127H	TO-99	0.1	45	150 2
LM126, LM226, LM326	±12	5	1	1	30	5	1-2.5	LM225, 226, 227H	TO-99	0.1	45	150 2
LM127, LM227, LM327	+5 and -12	5	1	1	30			LM325, 326, 327N LM325, 326, 327S	DIP ¹² SGS ¹²	0.1 0.1	- 12	150 55 1

¹ Operating temp range

LM100 series -55 to 125°C

LM200 series -25 to 85°C

LM300 series 0 to 70°C

² Max T_J = 150°C except 125°C for LM309, 320, 323, 345

³ Typ at 50-100% of rated I_{OUT}, 25°C, max V_{IN} change

⁴ Near zero to max rated I_{OUT}, 25°C pulse test

⁵ Max mV per volt of out voltage rating

⁶ Subtract (20 log V_{OUT}) for ripple rejection factor

⁷ ±10% available as LM340K R and LM340T R

⁸ ±10% available as LM78L CH and LM78L CZ

⁹ V_{OUT} = 6, 8, 18, 24 available only as LM320T

¹⁰ V_{IN} = 40 V for LM120H15 & LM120K15 series

¹¹ 1.5 A for V_{OUT} = 5 & 5.2 V

¹² DIP = 14 pin dual-in-line plastic pkg

SGS = Special DIP with heat sink

DATA SHEET SUMMARY

THIS SUMMARY SHEET IS A SUMMARY OF THE DATA SHEETS FOR THE PROJECT. IT IS NOT A SUBSTITUTE FOR THE DATA SHEETS. THE DATA SHEETS CONTAIN THE DETAILED DATA FOR EACH PROJECT. THE SUMMARY SHEET IS PROVIDED FOR YOUR INFORMATION AND FOR THE RECORD.

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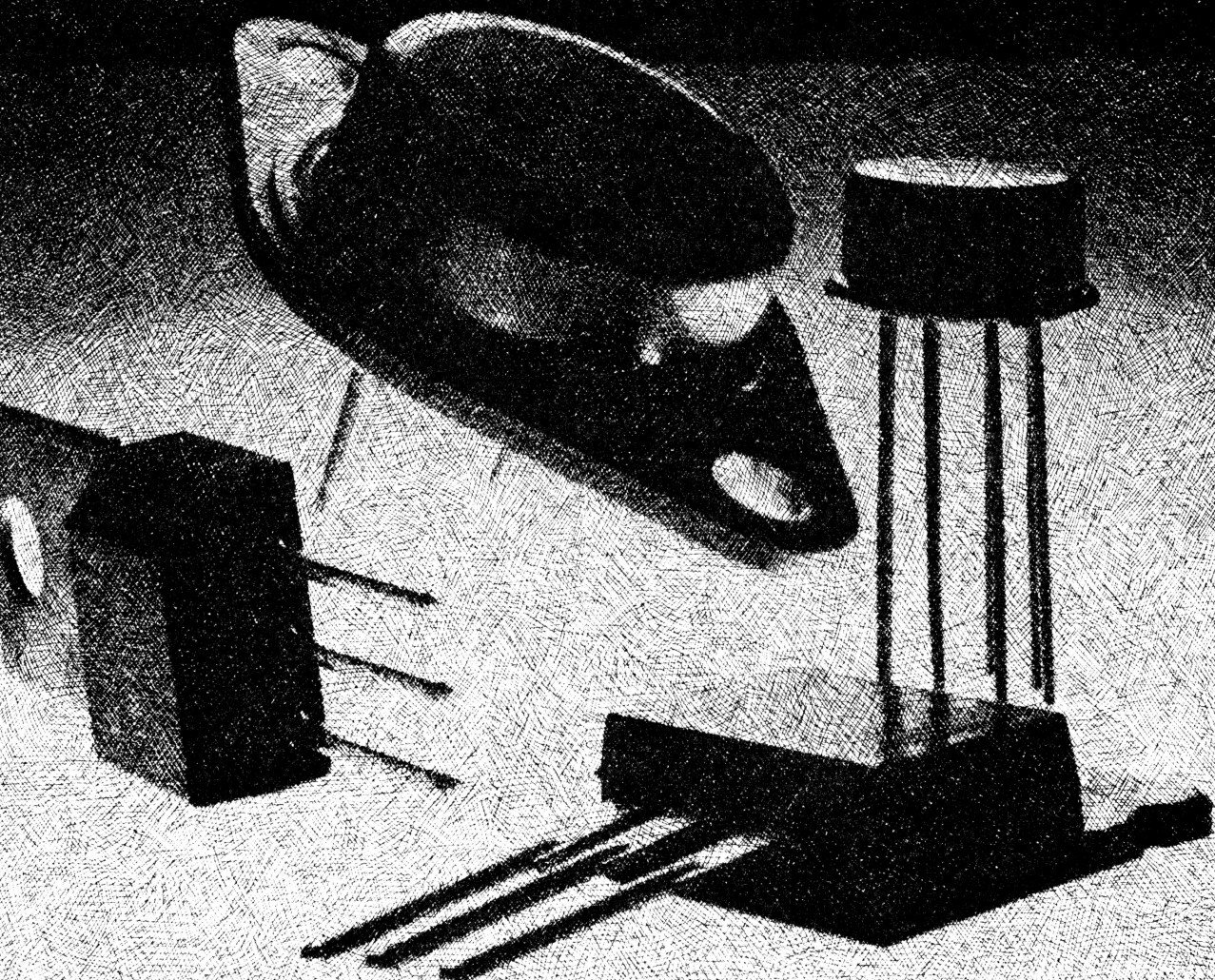
Project Name	Project Number	Project Description	Project Status	Project Manager	Project Start Date	Project End Date	Project Budget	Project Actual Cost	Project Variance
Project A	101	Project A Description	Completed	John Doe	10/10/10	10/10/10	\$100,000	\$100,000	\$0
Project B	102	Project B Description	In Progress	Jane Smith	10/10/10	10/10/10	\$200,000	\$150,000	\$50,000
Project C	103	Project C Description	On Hold	Bob Johnson	10/10/10	10/10/10	\$300,000	\$0	\$300,000
Project D	104	Project D Description	Completed	Alice Brown	10/10/10	10/10/10	\$400,000	\$400,000	\$0
Project E	105	Project E Description	In Progress	Charlie White	10/10/10	10/10/10	\$500,000	\$300,000	\$200,000
Project F	106	Project F Description	On Hold	Diana Green	10/10/10	10/10/10	\$600,000	\$0	\$600,000
Project G	107	Project G Description	Completed	Frank Black	10/10/10	10/10/10	\$700,000	\$700,000	\$0
Project H	108	Project H Description	In Progress	Grace Blue	10/10/10	10/10/10	\$800,000	\$600,000	\$200,000
Project I	109	Project I Description	On Hold	Henry Red	10/10/10	10/10/10	\$900,000	\$0	\$900,000
Project J	110	Project J Description	Completed	Ivy Purple	10/10/10	10/10/10	\$1,000,000	\$1,000,000	\$0

THIS SUMMARY SHEET IS A SUMMARY OF THE DATA SHEETS FOR THE PROJECT. IT IS NOT A SUBSTITUTE FOR THE DATA SHEETS. THE DATA SHEETS CONTAIN THE DETAILED DATA FOR EACH PROJECT. THE SUMMARY SHEET IS PROVIDED FOR YOUR INFORMATION AND FOR THE RECORD.

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Section 3.0

Product Selection Procedures



3.0 PRODUCT SELECTION PROCEDURES: FIXED VOLTAGE THREE-TERMINAL REGULATORS

3.1 DETERMINE:

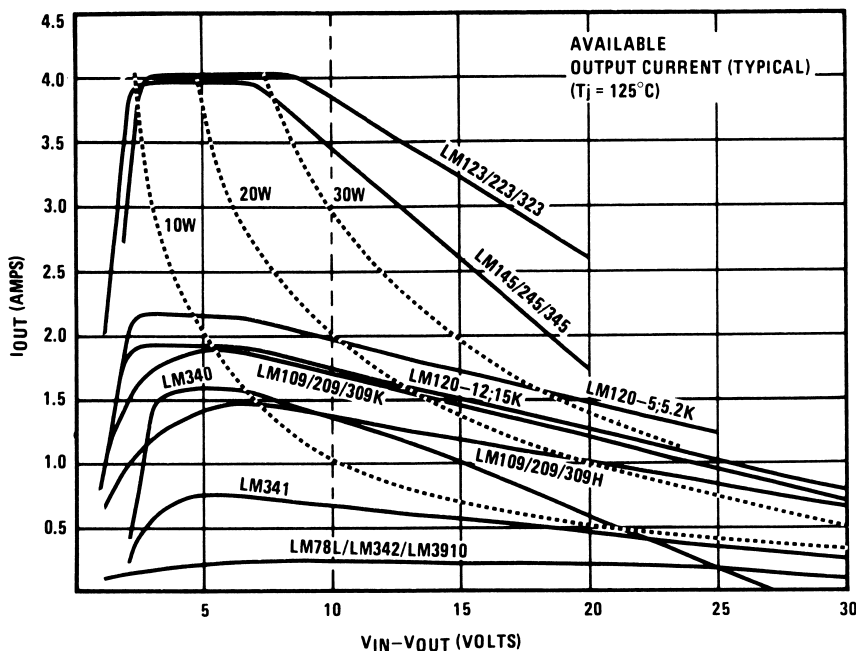
- a) V_{OUT} , required output voltage
- b) I_{OUT} , maximum output current
- c) V_{IN} , mean unregulated input voltage
- d) T_A , ambient temperature

3.2 SPECIFY:

- T_J , maximum operating junction temperature. For highest reliability, T_J should be 25°C or more below $T_{J(MAX)}$ as specified on the data sheet.

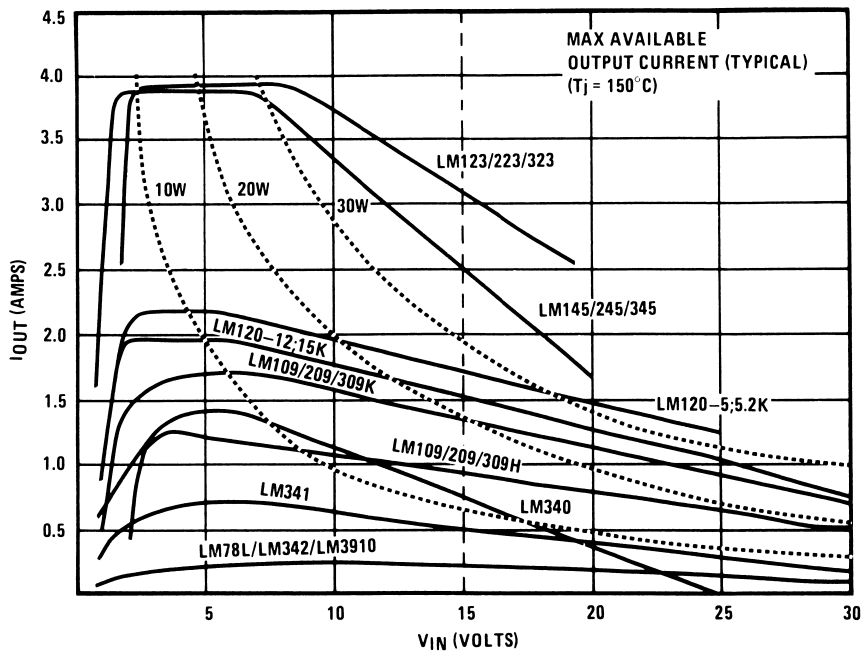
3.3 SELECT A REGULATOR

- a) Make preliminary selection based on step 1a and 1b above, from Figure 1.2, or the data sheet summary of Section 2.
- b) Verify this selection with Figure 3.1 or 3.2 to insure that the selected regulator will provide a peak current greater than I_{OUT} under the $V_{IN} - V_{OUT}$ operating conditions (peak current is limited by internal circuitry).
- c) Note also in Figure 3.1 or 3.2, the power dissipation curves, but choose packages from Figure 2.1 with P_D greater than dissipated power.
- d) Determine heat sink requirements from Section 5.



NOTE: Peak output currents for the LM120H are approximately half that of the LM120K.

FIGURE 3.1. Max Available Output Current at $T_J = 125^\circ\text{C}$

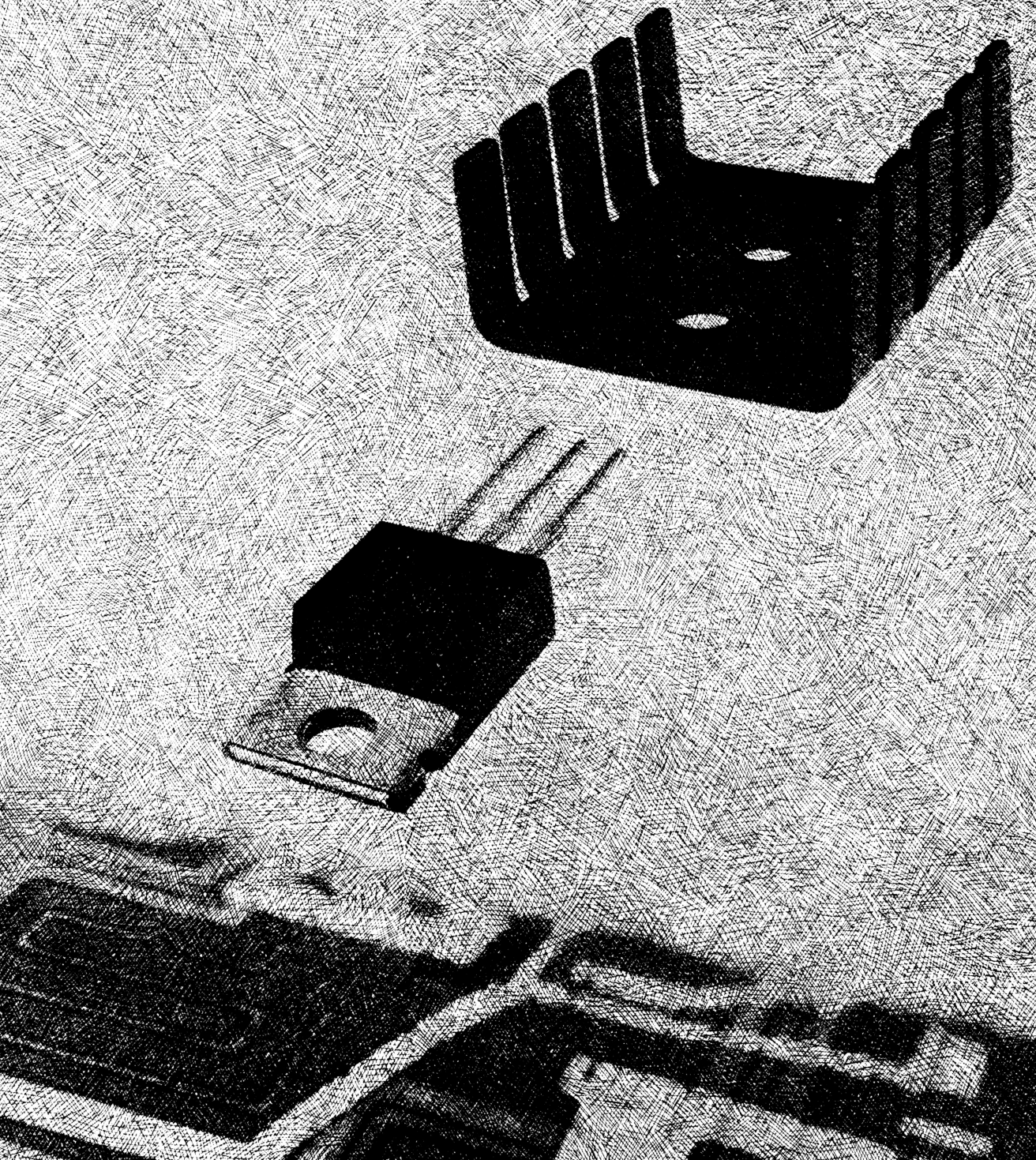


NOTE: The LM120H has output currents approximately half that of the LM120K.

FIGURE 3.2. Max Available Output Current at $T_j = 150^\circ\text{C}$

Section 4.0

Heat Flow & Thermal Resistance



4.0 HEAT FLOW & THERMAL RESISTANCE

4.1 HEAT FLOW

Heat can be transferred from the regulator package by three methods, as described and characterized in Table 4.1.

TABLE 4.1. Methods of Heat Flow

METHOD	DESCRIBING PARAMETERS
Conduction is the heat transfer method most effective in moving heat from junction to case and case to heat sink.	Thermal resistance θ_{JC} & θ_{CS} . Cross section, length and temperature difference across the conducting medium.
Convection is the effective method of heat transfer from case to ambient and heat sink to ambient.	Thermal resistance θ_{SA} and θ_{CA} . Surface condition, type of convecting fluid, velocity and character of the fluid flow (e.g., turbulent or laminar), and temperature difference between surface and fluid.
Radiation is important in transferring heat from cooling fins.	Surface emissivity and area. Temperature difference between radiating and adjacent objects or space. See Table 4.2 for values of emissivity.

4.2 THERMAL RESISTANCE

The thermal resistance between two points of a conductive system is expressed as

$$\theta_{12} = \frac{T_1 - T_2}{P_D} \text{ } ^\circ\text{C/W} \quad (4.1)$$

where subscript order indicates the direction of heat flow. A simplified heat transfer circuit for a cased semiconductor and heat sink system is shown in Figure 4.1. The circuit is valid only if the system is in thermal equilibrium (constant heat flow) and there are, indeed, single specific temperatures T_J , T_C , and T_X (no temperature distribution in junction, case, or heat sink). Nevertheless, this is a reasonable approximation of actual performance.

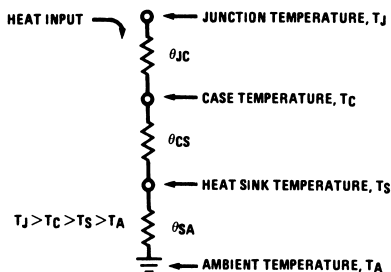


FIGURE 4.1. Semiconductor-Heat Sink Thermal Circuit

The junction-to-case thermal resistance θ_{JC} specified in the regulator data sheets depends upon the material and size of the package, die size and thickness, and quality of the die bond to the case or lead frame. The case-to-heat sink thermal resistance θ_{CS} depends on the mounting of the regulator to the heat sink and upon the

area and quality of the contact surface. Typical θ_{CS} for several packages and mounting conditions are as shown in Table 4.2.

The heat sink to ambient thermal resistance θ_{SA} depends on the quality of the heat sink and the ambient conditions. A listing of approximate θ_{SA} for a number of commercially available heat sinks appears in Section 5. θ_{SA} includes effects of both convection and radiation.

4.3 BASIC THERMAL CALCULATIONS

Cooling is normally required to maintain the worst case operating junction temperature T_J of the regulator below the specified maximum value $T_{J(MAX)}$. T_J can be calculated from known operating conditions. Rewriting Eqn 4.1, we find

$$\theta_{JA} = \frac{T_J - T_A}{P_D} \text{ } ^\circ\text{C/W} \quad (4.2)$$

$$T_J = T_A + P_D \theta_{JA} \text{ } ^\circ\text{C} \quad (4.3)$$

Where: $P_D = (V_{IN} - V_{OUT})I_{OUT} + V_{IN}I_Q$
 $\approx (V_{IN} - V_{OUT})I_{OUT}$

except for TO-92 package where $V_{IN}I_Q$ must be considered important.

I_Q = Regulator quiescent current

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}.$$

Data sheets usually provide a plot of Eqn 4.3 for several heat sinks. An example for the LM340T with $T_J = T_{J(MAX)} = 150^\circ\text{C}$ appears in Figure 4.2. Note that for the lower curve $\theta_{JA} = \theta_{CS} + \theta_{SA}$ while the upper curve is for $\theta_{JA} = \theta_{JC}$. Where the upper curve slope is zero, the limit is the arbitrary power dissipation rating instead of Eqn 4.1.

Table 4.2 Approximate Thermal Resistance, Case to Heat Sink θ_{CS} in $^{\circ}\text{C}/\text{W}$

Package	Direct contact	Contact with silicone grease	Contact with grease and mica washer
TO-3	0.5 - 0.7	0.3 - 0.5	0.4 - 0.6
TO-202	1.5 - 2.0	0.9 - 1.2	1.2 - 1.7
TO-220	1.0 - 1.3	0.6 - 0.8	0.8 - 1.1

Normally, we impose a full load operating junction temperature T_J at 25°C (or more) below specified $T_{J(\text{MAX})}$ at maximum expected T_A , and we need to find the required θ_{JA} from Eqn 4.2.

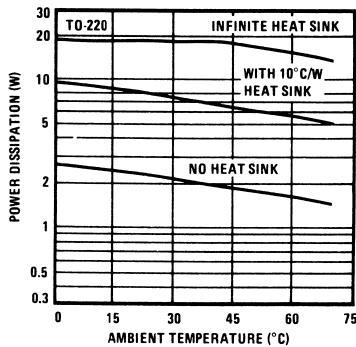


FIGURE 4.2. Power De-Rating Curves for LM340T

Section 5.0

Selection of Commercial Heat Sink





5.0 STANDARD HEAT SINK SELECTION PROCEDURES

5.1 COMPUTE TOTAL THERMAL RESISTANCE

Determine the total thermal resistance, junction to ambient $\theta_{JA(TOT)}$ necessary to maintain steady state T_J below the maximum value specified in Section 3.2.

$$\theta_{JA(TOT)} = \frac{T_J - T_A}{P_D} \text{ } ^\circ\text{C/W} \quad (5.1)$$

Under short circuit conditions, the internal thermal shutdown will limit T_J to about $175 \pm 15^\circ\text{C}$. Although this protects the device, prolonged operation at such temperatures can adversely effect device reliability (see Appendix 5, Reliability). If short circuit operation totaling more than 10-100 hours over system lifetime is expected, it is wise to use heat sinks which will limit short circuit T_J to $T_{J(MAX)}$. Accordingly, check operation with $V_{OUT} = 0$. The $\theta'_{JA(TOT)}$ necessary to maintain $T_J < T_{J(MAX)}$ under short circuit conditions is

$$\theta'_{JA(TOT)} = \frac{T_{J(MAX)} - T_A}{V_{IN} I_{SC}} \text{ } ^\circ\text{C/W} \quad (5.2)$$

where I_{SC} is read from Figure 3.2.

5.2 DETERMINE IF HEAT SINK IS REQUIRED

Refer to the thermal resistance, θ_{JC} and θ_{JA} , columns of the data sheet summary of Section 2.

- $\theta_{JA(TOT)} > \theta_{JC}$ must be met, otherwise a higher wattage device must be used or a boost circuit employed. (See Section 7, Applications, for boost circuits.)
- If $\theta_{JA(TOT)} > \theta_{JA}$, a heat sink is not required.
- If $\theta_{JC} < \theta_{JA(TOT)} < \theta_{JA}$, a heat sink is required.

5.3 SELECT A HEAT SINK

Choose a suitable heat sink from the selection guide, Table 5.1, or from manufacturers' specification data. The necessary conditions are that $\theta_{JA(TOT)}$ and $\theta'_{JA(TOT)}$ be less than θ_{JA} , as read from Table 2.1. The total thermal resistance is that from junction to case plus that from case to ambient or sink to ambient (neglecting that from case to sink, which is small).

$$\theta_{JA(TOT)} \approx \theta_{JC} + \theta_{SA} \text{ } ^\circ\text{C} \quad (5.3)$$

5.4 CHECK INPUT RIPPLE AND INPUT VARIATIONS

Insure that full-load $V_{IN(MIN)}$ does not allow $V_{IN} - V_{OUT}$ to fall below the dropout voltage of about 2 V. See individual data sheets if operation with $V_{IN} - V_{OUT} < 2$ V is required. Insure that no-load $V_{IN(MAX)}$ does not exceed the value listed on the data sheets or in the table of Section 2.

5.5 EXAMPLE CALCULATION

Given: $V_{OUT} = 5 \text{ V} \pm 5\%$ $V_{IN} = 15 \text{ V}$
 $I_{OUT(MAX)} = 0.7 \text{ A}$ Short circuit protected
 $T_A = 60^\circ\text{C}$ $T_J = 125^\circ\text{C}$

Select a suitable regulator and heat sink

- From Figure 1.2, initial selection is LM340T05, LM340K05, or LM309K.
- From Figure 3.1, at $V_{IN} - V_{OUT} = 10 \text{ V}$, it is clear that either the LM340 or LM309 will meet the maximum current required. The LM341P is also a possibility as seen from this figure, although a marginal one on the basis of $I_{OUT(MAX)}$, and should not be considered.

- Calculate necessary thermal resistance from Eqn 5.1

$$\theta_{JA(TOT)} = \frac{125 - 60}{10 \times 0.7} = \frac{65}{7} = 9.3^\circ\text{C/W}$$

Since $\theta_{JA(TOT)}$ must be greater than θ_{JC} as read from Table 2.1, the LM341P is now clearly eliminated as a possibility. If not already eliminated in step (a) above, the LM309H would also drop out at this time. The selection is still limited to the LM340T, LM340K, or LM309K.

- Since $\theta_{JA(TOT)}$ is less than θ_{JA} for any of these parts, a heat sink is required.
- From Figure 3.2, $I_{OUT(MAX)}$ is 0.75 A or 1.4 A for the LM340 or LM309K respectively, under short circuit conditions. If extended periods of short circuit operation are expected, calculate $\theta'_{JA(TOT)}$ from Eqn 5.2.

$$\theta'_{JA(TOT)} = \frac{150 - 60}{15 \times 1.4} = \frac{90}{21} = 4.3^\circ\text{C/W for LM309}$$

$$\theta'_{JA(TOT)} = \frac{150 - 60}{15 \times 0.75} = \frac{90}{11.25} = 8^\circ\text{C/W for LM340}$$

The worst case heat sink requirement is then for short circuit conditions, and the LM340 has a lesser heat sink requirement. Further selection will depend upon hermeticity and mounting requirements. The T package is TO-220 plastic and the K package is TO-3 hermetic.

- Choosing the LM340T, calculate heat sink thermal resistance from Eqn 5.4 where θ_{JC} is found from Table 2.1.

$$\theta_{SA} = \theta'_{JA(TOT)} - \theta_{JC} = 8 - 4 = 4^\circ\text{C/W} \quad (5.4)$$

If we were to accept a $T_J > 150^\circ\text{C}$ for short circuit conditions, calculations based on $\theta_{JA(TOT)}$ would yield a $\theta_{SA} = 5.3^\circ\text{C/W}$. If an LM309K had been selected, a $\theta_{SA} = 6.3^\circ\text{C/W}$ would be all that is required.

- Referring to the heat sink selection guide, Table 5.1, for the TO-220 package we see that only the IERC HP3 series will come close to the 4°C/W figure. A 4°C/W heat sink is widely available for the TO-3 or K package.
- For detailed information on heat sink design, see Section 6.

TABLE 5.1 Heat Sink Selection Guide

No attempt has been made to provide a complete list of all heat sink manufacturers. This list is only representative.

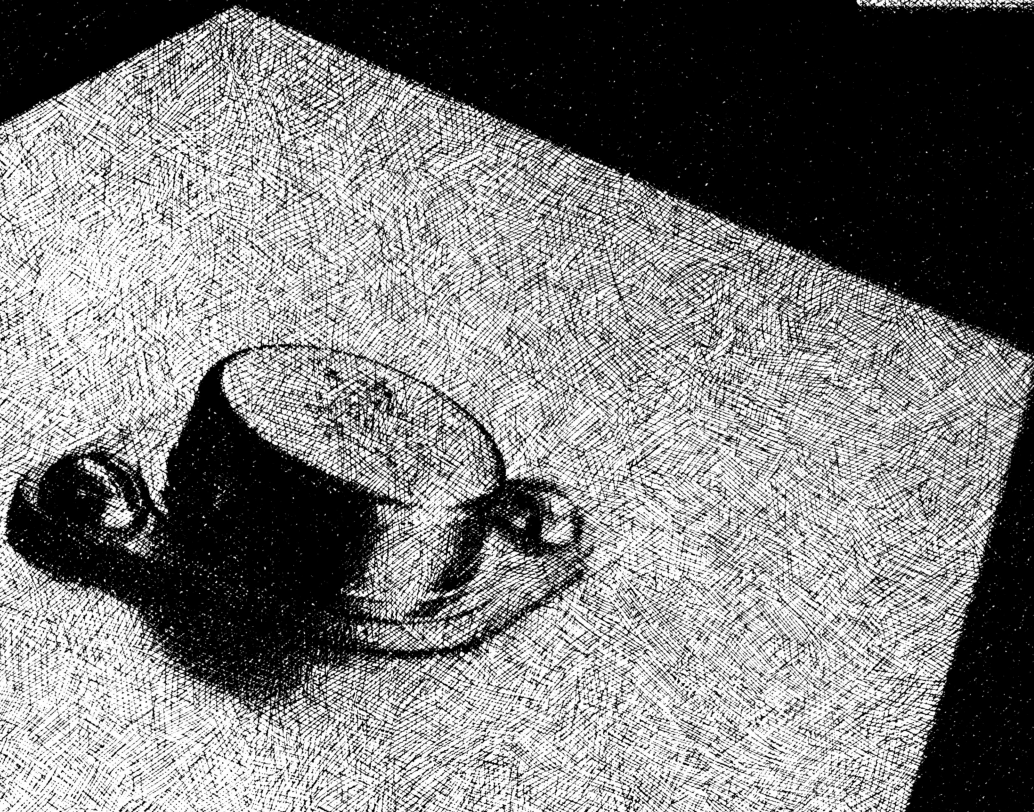
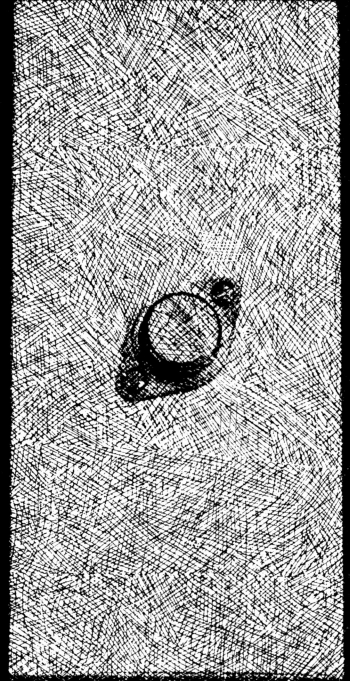
θ_{SA} Approx ¹ (°C/W)	Manufacturer & Type	θ_{SA} Approx ¹ (°C/W)	Manufacturer & Type	θ_{SA} Approx ¹ (°C/W)	Manufacturer & Type
For TO-202 Packages			For TO-3 Packages		
12.5 - 14.2	Staver V4-3-192	12	Thermalloy 1101, 1103 Series	0.4 (9" length)	Thermalloy (Extruded) 6590 Series
13	Staver V5-1	12 - 16	Wakefield 260-5 Series	0.4 - 0.5	Thermalloy (Extruded) 6660, 6560 Series
15.1 - 17.2	Staver V4-3-128	15	Staver V3A-5 Series	0.56 - 3.0	Wakefield 400 Series
19	Thermalloy 6106 Series	22	Thermalloy 1116, 1121, 1123 Series	0.6 (7.5" length)	Thermalloy (Extruded) 6470 Series
20	Staver V6-2	22	Thermalloy 1130, 1131, 1132 Series	0.7 - 1.2	Thermalloy (Extruded) 6423, 6443, 6441, 6450 Series
25	Thermalloy 6107 Series	24	Staver F5-5C	1.0 - 5.4	Thermalloy (Extruded) 6427, 6463, 6176, 6129, 6141, 6169, 6135, 6442 Series
37	IERC PA1-7CB with PVC-1B Clip	26 - 30	IERC Thermal Links	1.9	IERC E2 Series (Extruded)
40 - 42	Staver F7-3	27 - 83	Wakefield 200 Series	2.1	IERC E1, E3 Series (Extruded)
40 - 43	Staver F7-2	28	Staver F5-5B	2.3 - 4.7	Wakefield 600 Series
42	IERC PA2-7CB with PVC-1B Clip	30	Thermalloy 2227 Series	4.2	IERC HP3 Series
42 - 44	Staver F7-1	34	Thermalloy 2228 Series	4.5	Staver V3-5-2
For TO-220 Packages			IERC Clip Mount Thermal Link	5 - 6	IERC HP3 Series
4.2	IERC HP3 Series	35	Staver F5-5A	5.2 - 6.2	Thermalloy 6103 Series
5 - 6	IERC HP1 Series	39	Wakefield 296 Series	5.6	Staver V3-3-2
6.4	Staver V3-7-225	42	Staver F6-5, F6-5L	5.8 - 7.9	Thermalloy 6001 Series
6.5 - 7.5	IERC VP Series	45 - 65	Thermalloy 2215 Series	5.9 - 10	Wakefield 680 Series
8.1	Staver V3-5	46	Thermalloy 2225 Series	6	Wakefield 390 Series
8.8	Staver V3-7-96	50	IERC Fan Tops	6.4	Staver V3-7-224
9.5	Staver V3-3	50 - 55	Thermalloy 2205 Series	6.5 - 7.5	IERC UP Series
10	Thermalloy 6032, 6034 Series	51	Thermalloy 2211 Series	8	Staver V1-5
12.5 - 14.2	Staver V4-3-192	53	Thermalloy 2210 Series	8.1	Staver V3-5
13	Staver V5-1	55	Thermalloy 1129 Series	8.8	Staver V3-7-96
15	Thermalloy 6030 Series	56	Thermalloy 2226 Series	8.8 - 14.4	Thermalloy 6013 Series
15.1 - 17.2	Staver V4-3-128	58	Staver F1-5	9.5	Staver V3-3
16	Thermalloy 6106 Series	60	Thermalloy 1115 Series	9.5 - 10.5	IERC LA Series
18	Thermalloy 6107 Series	68		9.8 - 13.9	Wakefield 630 Series
19	IERC PB Series	72		10	Staver V1-3
20	Staver V6-2			13	Thermalloy 6117
25	IERC PA Series				
26	Thermalloy 6025 Series				
For TO-92 Packages					
30	Staver F2-7				
46	Staver F5-7A, F5-8-1				
50	IERC RUR Series				
57	Staver F5-7D				
65	IERC RU Series				
72	Staver F1-7				
85	Thermalloy 2224 Series				

Staver Co, Inc.: 41-51 N. Saxon Ave, Bay Shore, NY 11706
 IERC: 135 W. Magnolia Blvd, Burbank, CA 91502
 Thermalloy: PO Box 34829, 2021 W. Valley View Ln, Dallas TX
 Wakefield Engin Ind: Wakefield MA 01880

¹ All values are typical as given by mfr. or as determined from characteristic curves supplied by mfr.

Section 6.0

Custom Heat Sink Design



6.0 CUSTOM HEAT SINK DESIGN

6.1 IS A CUSTOM DESIGN NECESSARY?

The required θ_{SA} was determined in Section 5. Even though many heat sinks are commercially available, it is sometimes more practical, more convenient, or more economical to mount the regulator to chassis, to an aluminum or copper fin, to an aluminum extrusion, or to a custom heat sink. In such cases, design a simple heat sink.

6.2 SIMPLE RULES

- Mount cooling fin vertically where practical for best convective heat flow.
- Anodize, oxidize, or paint the fin surface for better radiation heat flow; see Table 6.1 for emissivity data.
- Use 1/16" or thicker fins to provide low thermal resistance at the regulator mounting where total fin cross-section is least.

6.3 FIN THERMAL RESISTANCE

The heat sink-to-ambient thermal resistance of a vertically mounted symmetrical square or round fin (see Figure 6.1) in still air is:

$$\theta_{SA} = \frac{1}{2H^2\eta(h_c + h_r)} \text{ } ^\circ\text{C/W} \quad (6.1)$$

Where: H = height of vertical plate in inches

η = fin effectiveness factor

h_c = convection heat transfer coefficient (6.2)

h_r = radiation heat transfer coefficient (6.3)

$$h_c = 2.21 \times 10^{-3} \left(\frac{T_S - T_A}{H} \right)^{1/4} \text{ W/in}^2\text{ } ^\circ\text{C}$$

$$h_r = 1.47 \times 10^{-10} E \left(\frac{T_S + T_A}{2} + 273 \right)^3 \text{ W/in}^2\text{ } ^\circ\text{C}$$

Where: T_S = temperature of heat sink at regulator mounting, in $^\circ\text{C}$

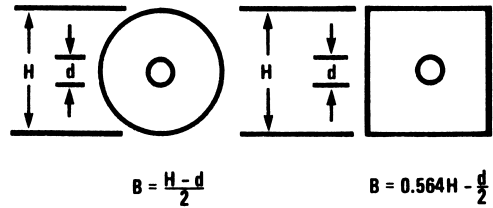
T_A = ambient temperature in $^\circ\text{C}$

E = surface emissivity (see Table 6.1)

Fin effectiveness factor η includes the effects of fin thickness, shape, thermal conduction, et. al. It may be determined from the nomogram of Figure 6.2.

TABLE 6.1. Emissivity Values for Various Surface Treatments

SURFACE	EMISSION, E
Polished Aluminum	0.05
Polished Copper	0.07
Rolled Sheet Steel	0.66
Oxidized Copper	0.70
Black Anodized Aluminum	0.7-0.9
Black Air Drying Enamel	0.85-0.91
Dark Varnish	0.89-0.93
Black Oil Paint	0.92-0.96



Note: For $H \gg d$, using $B = H/2$ is a satisfactory approximation for either square or round fins.

FIGURE 6.1. Symmetrical Fin Shapes

The procedure for use of the nomogram of Figure 6.2 is as follows:

- Specify fin height H as first approximation.
- Calculate $h = h_r + h_c$ from Eqns 6.2 and 6.3.
- Determine α from values of h and fin thickness x (line a).
- Determine η from values of B (from Figure 6.1) and α (line b).

The value of η thus determined is valid for vertically mounted symmetrical square or round fins (with $H \gg d$) in still air. For other conditions, η must be modified as follows:

Horizontal mounting - multiply h_c by 0.7.

Horizontal mounting where only one side is effective - multiply η by 0.5 and h_c by 0.94

For 2:1 rectangular fins - multiply h by 0.8.

For non-symmetrical fins where the regulator is mounted at the bottom of a vertical fin - multiply η by 0.7.

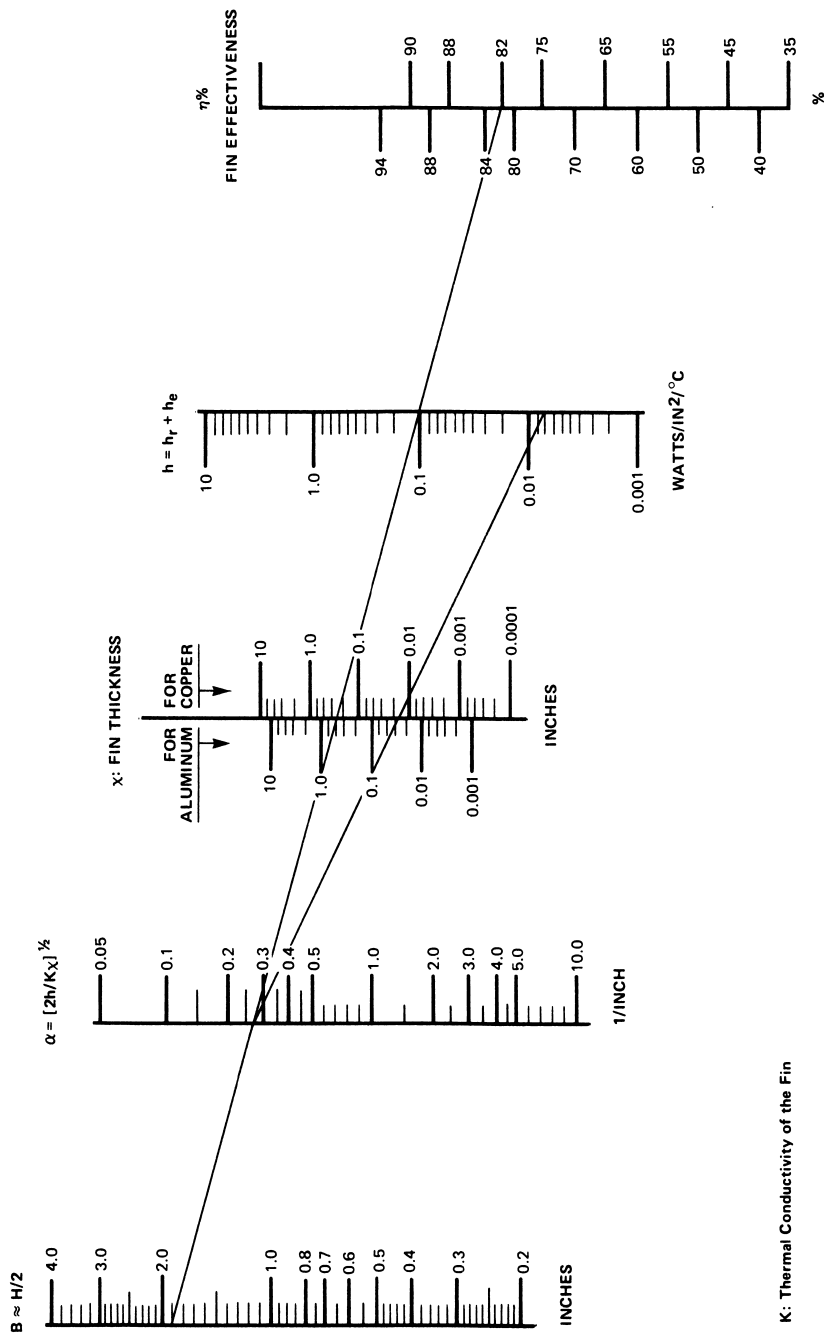
6.4 FIN DESIGN

- Establish initial conditions T_A and desired θ_{SA} as determined in Section 5.3.
- Determine T_S at contact point with the regulator by rewriting Eqn 4.1.

$$\theta_{JC} + \theta_{CS} = \frac{T_J - T_S}{P_D} \quad (6.4)$$

$$T_S = T_J - (\theta_{JC} + \theta_{CS})(V_{IN} - V_{OUT})I_{OUT} \approx T_J - \theta_{JC}(V_{IN} - V_{OUT})I_{OUT} \quad (6.5)$$

- Select fin thickness, $x > 0.0625$ " and fin height, H .
- Determine h_c and h_r from Eqns 6.2 and 6.3.
- Find fin effectiveness factor η from Figure 6.2.
- Calculate θ_{SA} from Eqn 6.1.
- If θ_{SA} is too large or unnecessarily small, choose a different height and repeat steps (c) through (f).



K: Thermal Conductivity of the Fin

FIGURE 6.2. Fin Effectiveness Nomogram for Symmetrical, Flat, Uniformly-Thick, Vertically Mounted Fins

6.5 DESIGN EXAMPLE

Design a symmetrical square vertical fin of black anodized 1/16" thick aluminum to have a thermal resistance of 4°C/W. LM340T-05 operating conditions are:

$$\begin{aligned} \text{a) } T_J &= 125^\circ\text{C} & T_A &= 60^\circ\text{C} \\ V_{IN} &= 15 \text{ V} & V_{OUT} &= 5 \text{ V} \\ I_{OUT} &= 0.8 \text{ A} & \text{Neglect } \theta_{CS} & \end{aligned}$$

$$\text{b) } T_S = 125^\circ\text{C} - 4^\circ\text{C/W}(15 \text{ V} - 5 \text{ V})0.8 \text{ A} = 93^\circ\text{C}$$

$$\text{c) } x = 0.0625'' \text{ from initial conditions. } E = 0.9 \text{ from Table 6.1.}$$

Select $H = 3.5''$ for first trial (experience will simplify this step).

$$\text{d) } h_c = 2.21 \times 10^{-3} \left(\frac{93 - 60}{3.5} \right)^{1/4}$$

$$= 3.86 \times 10^{-3} \text{ W/}^\circ\text{C-in}^2$$

$$h_r = 1.47 \times 10^{-10} \times 0.9 \left(\frac{93 + 60}{2} + 273 \right)^3$$

$$= 5.6 \times 10^{-3} \text{ W/}^\circ\text{C-in}^2$$

$$h = h_c + h_r = 9.46 \times 10^{-3} \text{ W/}^\circ\text{C-in}^2$$

$$\text{e) } \eta = 0.84 \text{ from Figure 6.2.}$$

$$\text{f) } \theta_{SA} = \frac{10^3}{2 \times 12.3 \times 0.84 \times 9.46} = 5.1^\circ\text{C/W,}$$

which is too large.

g) A larger fin is required, probably by about 40% in area. Accordingly, using a fin of 4.25" square, a new calculation is made.

$$\text{d') } h_c = 2.21 \times 10^{-3} \left(\frac{0.33}{4.2} \right)^{1/4} = 3.7 \times 10^{-3}$$

$$h_r = 5.6 \times 10^{-3} \text{ as before}$$

$$h = 9.3 \times 10^{-3}$$

$$\text{e') } \eta = 0.75 \text{ from Figure 6.2}$$

$$\text{f') } \theta_{SA} = \frac{10^3}{2 \times 18 \times 0.75 \times 9.3} = 3.98^\circ\text{C/W,}$$

which is satisfactory.

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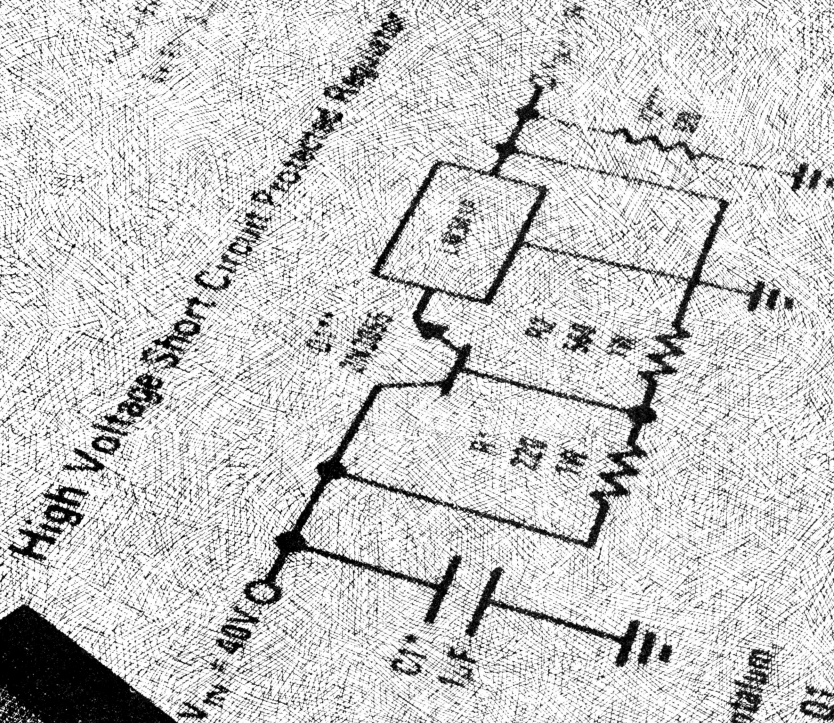
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Section 7.0

Application Circuits & Description Information



Solid tantulum

*Heat sink Q1.

***Since the 1940s

7.0 APPLICATIONS

Voltage regulator use can be expanded beyond that of the simple three-terminal fixed voltage regulator. Some of the circuits which are practical and useful are described in this section. Pertinent equations are included rather than providing fixed component values as the circuits are equally applicable to all regulators within a family.

7.1 POSITIVE REGULATORS

7.1.1 Basic Regulator

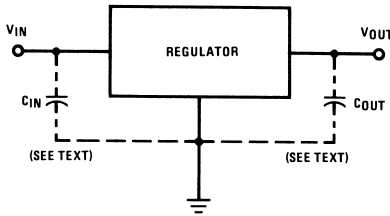


FIGURE 7.1. Basic Regulator Connection

Normal connections are indicated in Figure 7.1. If the regulator is located more than two inches from the supply filter capacitor, a supply bypass capacitor is required to maintain stability (much as is the case with op-amps). This should be an 0.22 μ F or larger disc ceramic, 2 μ F or larger solid tantalum, or 25 μ F or larger aluminum electrolytic capacitor (the LM120 and LM123 series require the solid tantalum or aluminum electrolytics). Progressively larger values are required of ceramic, solid tantalum and aluminum electrolytic capacitors because the effective series resistance ESR increases respectively in each type capacitor. The LM120 series alone of all the group requires an output capacitor to insure stable operation. The others are stable when operating into a resistive load. The LM120 output capacitor should be a 1 μ F or larger solid tantalum or 25 μ F or larger aluminum electrolytic. Transient response of all the regulators is improved when output capacitors are added. To minimize high-frequency noise, an 0.1 μ F output capacitor is recommended on the LM78LXX and LM3910 series.

7.1.2 Current Source

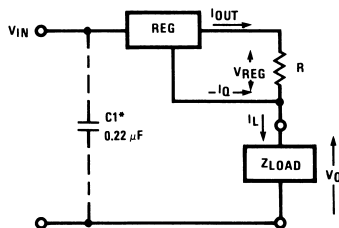


FIGURE 7.2. Current Source

A constant output current I_L is delivered to a variable load impedance Z_L .

$$I_L = \frac{V_{REG}}{R} + I_Q \quad (7.1)$$

$$\text{for } 0 \leq Z_L \leq \frac{V_{IN} - (V_{REG} + V_{dropout})}{I_L}$$

The output impedance is:

$$Z_O = \frac{\Delta V_O}{\Delta I_L} = \frac{1}{\frac{\Delta I_Q}{\Delta V_{IN}} + \frac{L'_r}{R}} \quad (7.2)$$

where: $\frac{\Delta I_Q}{\Delta V_{IN}}$ = quiescent current change per volt of input voltage change of the regulator

$L'_r = \frac{\Delta V_O}{\Delta V_{IN}}$ = line regulation, the change in regulator output per volt of input voltage change at a given I_O

7.1.3 High Current Regulator

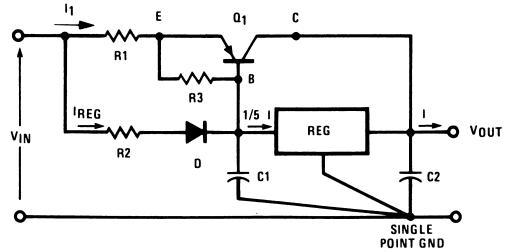


FIGURE 7.3. High Current Regulator with Short Circuit Limit During Output Shorts

This current boost circuit takes advantage of the internal current limiting characteristics of the regulator to provide short-circuit current protection for the booster as well. The regulator and Q_1 share load current in the ratio set between R_2 and R_1 if $V_D = V_{BE}(Q_1)$.

$$I_1 = \frac{R_2}{R_1} I_{REG} \quad (7.3)$$

During output shorts

$$I_{1(SC)} = \frac{R_2}{R_1} I_{REG(SC)} \quad (7.4)$$

If the regulator and Q_1 have the same thermal resistance θ_{JC} and the pass transistor heat sink has R_2/R_1 times the capacity of the regulator heat sink, the thermal protection (shutdown) of the regulator will also be extended to Q_1 . Some suggested transistors are listed below.

Q_1	D	I_1	I_{REG}	R_2/R_1	R_3
2N4398	1N4719	≥ 3 A	1 A	≥ 3	5 - 10 Ω
NSD32	1N4719	2 A	1 A	2	5 - 10 Ω
NSDUS1A	1N4003	1 A	0.5 A	2	5 - 10 Ω

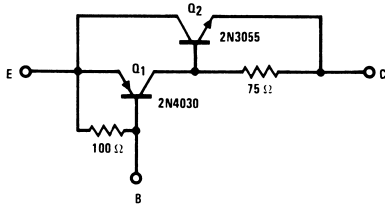


FIGURE 7.4. Equivalent of Power PNP Transistor

The minimum input-to-output voltage differential of the regulator circuit is increased by a diode drop plus the V_{R1} drop. For high current applications a low priced PNP/NPN combination may be used to replace the expensive single PNP 2N4398 as illustrated in Figure 7.4.

7.1.4 Adjustable Output Voltage

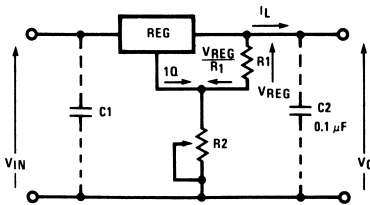


FIGURE 7.5. Adjustable V_{OUT}

A fraction of the regulator current V_{REG}/R_1 is used to raise the ground pin of the regulator and provide, through voltage drop across R_2 , an adjustable output voltage.

$$V_O = V_{REG} + R_2(I_Q + \frac{V_{REG}}{R_1}) \quad (7.5)$$

Line regulation is

$$\frac{\Delta V_O}{\Delta V_{IN}} = (L'_r)(\frac{R_1 + R_2}{R_1}) + (\frac{\Delta I_Q}{\Delta V_{IN}})R_2 \quad (7.6)$$

Load regulation is

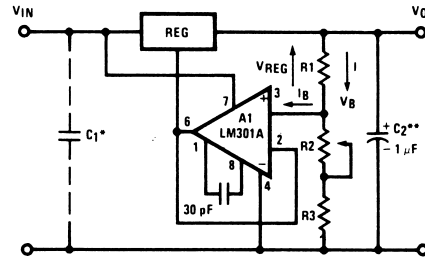
$$\frac{\Delta V_O}{\Delta I_L} = (L_r)(\frac{R_1 + R_2}{R_1}) + (\frac{\Delta I_Q}{\Delta I_O})R_2 \quad (7.7)$$

where: $L_r = \frac{\Delta V_O}{\Delta I_O}$, the regulator load regulation per amp of load change

$\frac{\Delta I_Q}{\Delta I_O}$ = quiescent current change per amp of load current change

$\frac{\Delta I_Q}{\Delta V_{IN}}$ = quiescent current change per volt of input voltage change

7.1.5 Variable Output Voltage



* Required if the regulator far from power supply filter
** Solid tantalum

FIGURE 7.6. Variable Output Regulator

The ground terminal of the regulator is raised above common by an amount equal to the voltage applied at the non-inverting input of the op-amp. For $I \gg I_B$, the output voltage is:

$$V_O = (\frac{R_1 + R_2 + R_3}{R_1}) V_{REG} \quad (7.8)$$

The minimum output voltage will be determined by the V_{REG} and $V_{B(MIN)}$, where $V_{B(MIN)}$ is the op-amp common-mode voltage lower limit (≈ 2 V for LM301A used with single supply).

$$V_{O(MIN)} = V_{REG} + V_{B(MIN)} \quad (7.9)$$

$$\text{when } R_2 = 0, \quad \frac{R_3}{R_1} = \frac{V_{B(MIN)}}{V_{REG}} \quad (7.10a)$$

$$V_{O(MAX)} = (\frac{R_1 + R_2(MAX) + R_3}{R_1}) V_{REG} = V_{IN} - V_{dropout} \quad (7.10b)$$

To choose R_1 , R_2 , R_3 for a specified V_{IN} , start with an arbitrary value for R_1 . Determine R_2 and R_3 from Eqn 7.10 and finally check to insure that

$$\frac{V_{O(MIN)}}{R_1 + R_3} \gg I_B, \quad \frac{V_{O(MAX)}}{R_1 + R_2 + R_3} \gg I_B$$

Example: $V_{IN} = 25$ V LM341P-05

$V_O = 7.23$ V $R_1 = 3$ K

$R_2 = 10$ K

$R_3 = 1.2$ K

The load and line regulation can be determined by:

$$\frac{\Delta V_O}{\Delta V_{IN}} = (L'_r)(\frac{R_1 + R_2 + R_3}{R_1}) \quad (7.11)$$

$$\frac{\Delta V_O}{\Delta I_L} = (L_r)(\frac{R_1 + R_2 + R_3}{R_1}) \quad (7.12)$$

The ΔI_Q factor (see previous paragraph) is neglected because the op-amp output impedance is very low.

7.1.6 Variable Output Voltage with $V_{O(MIN)} \approx 0$

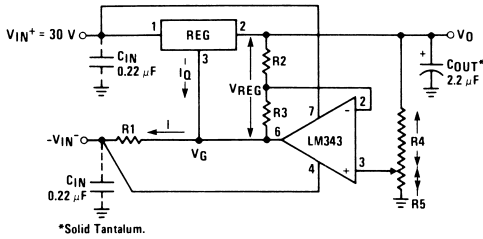


FIGURE 7.7. Variable Output Voltage of 0.5 - 28 V

A wide range of output voltages can be obtained with the circuit of Figure 7.7. A 0- to 20-volt supply can be built using a -7-volt supply and a conventional op-amp. For higher output voltages, a high-voltage op-amp, such as LM143, is required. If

$$R_2 + R_3 = R_4 + R_5 = R, \quad \text{and} \quad R_2/R_3 = 1/10,$$

$$\text{then } V_O = V_{REG} \left(\frac{R_2}{R_4} \right) = V_{REG} \left(\frac{1}{11} \right) \left(\frac{R_4 + R_5}{R_4} \right) \quad (7.13)$$

Since V_O is inversely proportional to R_4 , low output voltages can be very accurately set. The required R_1 is

$$R_1 = \frac{V_{IN-}}{I_Q}$$

The $V_{O(MAX)}$ is dependent on V_{IN} and $V_{dropout}$, provided that the amplifier can source the current required to raise V_G to $V_O - V_{REG}$.

Example: $V_{IN-} = -15 \text{ V}$ $R_1 = 2.1 \text{ K}$
 $V_{IN+} = +30 \text{ V}$ $R_2 = 910 \text{ } \Omega$
 $V_O = 0.5\text{-}28 \text{ V}$ $R_3 = 9.1 \text{ K}$
 LM340K-05 $R_4 + R_5 = 10 \text{ K}$

7.1.7 High Input Voltage

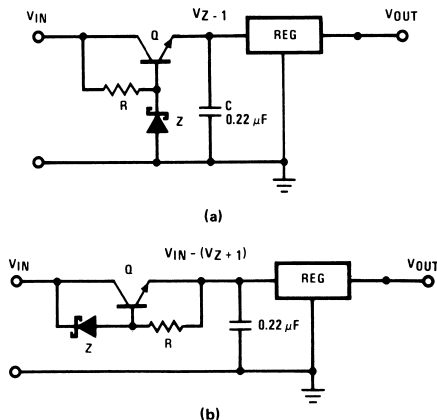


FIGURE 7.8. High Input Voltage

For input voltages higher than $V_{IN(MAX)}$ as specified for the regulator, a transistor/low-power zener combination can be used (instead of an expensive power zener) to reduce the input voltage seen by the regulator. Transistor Q conducts full load current, and therefore requires a power device with adequate heat sink.

Example: In Figure 7.8b

$V_{IN} = 48 \text{ V}$ LM341P-15
 $I_L = 400 \text{ mA}$ $Z = 1N4745 (16 \text{ V})$

Q would dissipate 7 W, therefore use an NSD31 power transistor. For higher dissipation, use a 2N3055.

7.1.8 High Output Voltage

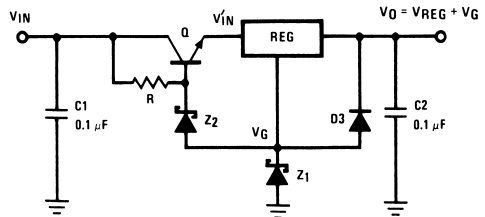


FIGURE 7.9. High-Voltage Regulator

With the circuit of Figure 7.6, one can obtain high output voltages if a high-voltage op-amp is used (LM343). Another approach is to raise the ground terminal with a zener diode as illustrated in Figure 7.9. Transistor Q and Z_2 set $V'_{IN} \approx V_{Z2} + V_{Z1} - 1 \text{ V}$. D_3 aids full load start-up and also holds V_G to a diode drop above ground during short circuits, thus protecting the regulator from high input-to-output voltage differentials.

Example: LM340T-24 $Z_1 = 1N5359 (24 \text{ V})$
 $V_{IN} = 80 \text{ V}$ $Z_2 = 1N5365 (36 \text{ V})$
 $V_O = 48 \text{ V}$ $Q = 2N3055$
 $R = 600 \text{ } \Omega$

Under short-circuit conditions, V'_{IN} reduces to 35 V.

Figure 7.10 illustrates another circuit for a high-voltage regulator with better input voltage limiting under short circuit conditions. In normal operation, Q_2 is OFF and Q_1 conducts full load current. Q_2 saturates when the output is shorted, thus dropping the voltage at Q_1 base and limiting regulator V'_{IN} to a low value. D_1 (1N914) protects Q_2 from base-emitter breakdown. If an output capacitor is used, D_2 protects the regulator from V_{IN}

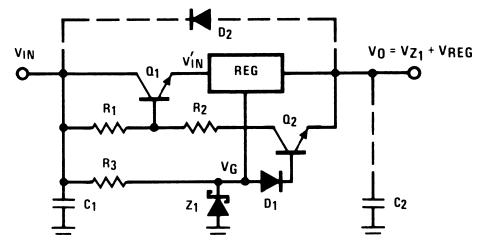


FIGURE 7.10. High-Voltage Regulator

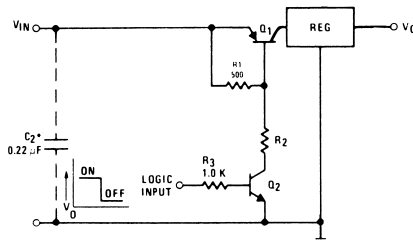
shorts which would temporarily reverse $V_{IN} - V_O$ polarity. A large input capacitor C_1 should be included in the circuit to insure that V_G will rise along with V_{IN} at turn-on. Since Q_1 does not switch OFF under short-circuit load, it must be a power device with heat sink adequate to handle the short circuit dissipation.

Example: LM340T-24

$Z_1 = 1N5359$ (24 V) $R_1 = 300 \Omega$, 10 W
 $V_{IN} = 60$ V $Q_1 = 2N3055$ $R_2 = 60 \Omega$, 4 W
 $V_O = 48$ V $Q_2 = 2N3643$ $R_3 = 1500 \Omega$, 4 W

Under short circuit conditions V'_{IN} reduces to 9 V.

7.1.9 Electronic Shutdown



* Required if regulator far from power supply filter

FIGURE 7.11. Electronic Shutdown Circuit

Electronic shutdown in three-terminal regulators is done by simply opening the input circuit using a transistor switch. Q_1 operates as the switch which is driven by Q_2 . The control voltage V_C can be TTL compatible with the use of $R_3 = 1K$. R_1 is a biasing resistor, and R_2 can be calculated as

$$R_2 = \frac{V_{IN} - 1V}{I_O} \beta_{SAT}(Q1) \quad (7.14)$$

Figure 7.12 illustrates a short-circuit dependent power shutdown circuit with reduced heat sink requirements under short-circuit conditions.

When the power is first applied, Q_2 turns ON and saturates Q_1 . The regulator output ramps up to turn Q_3 ON, which turns Q_2 OFF (V_C should be $> V_A$), thus maintaining Q_1 in the ON state.

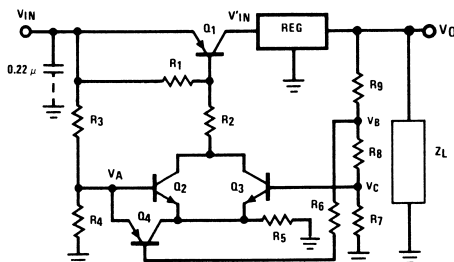


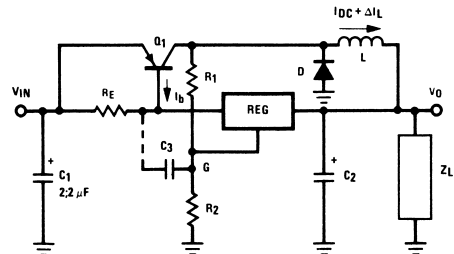
FIGURE 7.12. Output Dependant Electronic Shutdown on High Voltage Regulator

When the output is shorted, Q_3 turns OFF, Q_4 turns ON to clamp Q_2 OFF. Q_1 loses base drive and so opens to isolate the regulator from V_{IN} . When the short circuit is removed, Q_4 loses some base drive and enables Q_2 to re-start the regulator. Q_1 always operates as a switch and needs no heat sinking. Q_2 and Q_3 need not be matched. Q_4 may be any small signal PNP transistor. The entire circuit (less regulator) fits easily on a one-inch square PC board.

Example: LM340K-24

$V_{IN} = 36$ V $Q_1 = NSD32$ $R_1 = 500 \Omega$
 $V_O = 24$ V $Q_2 = 2N4141$ $R_2 = 250 \Omega$, 2 W
 $I_O = 1$ A $Q_3 = 2N4141$ $R_3 = 3300 \Omega$
 $V_A = 2.5$ V $Q_4 = 2N2906$ $R_4 = 240 \Omega$
 $V_B = 8$ V $R_5 = 62 \Omega$
 $V_C = 4.8$ V $R_6 = 2K$
 $R_7 = 1K$
 $R_8 = 680 \Omega$
 $R_9 = 3.3K$

7.1.10 Switching Regulator



$$\text{Ripple} \approx V_{IN} \frac{R_2}{R_1 + R_2}$$

FIGURE 7.13. Switching Regulator

A switching power supply may be constructed with a three-terminal regulator, as shown in Figure 7.13. Since no reference pin is available, the positive feedback loop (R_1, R_2) will be connected to the ground terminal. With the supply ON, the load draws current through the regulator, which turns ON Q_1 and applies power to the inductor. As the current through L increases, the regulator supplies less and less current to the load and finally turns Q_1 OFF. See National Semiconductor Application Note AN-2 for further design information on switching regulator design. To optimize the efficiency of the regulator, any DC current through R_E should be minimized. This is done by appropriate choice of R_E , that is:

$$I_{RE} + I_b = \frac{V_{BE}(SAT)}{R_E} + I_b \approx \frac{V_{IN} - V_O}{2L} t_{on} \quad (7.15)$$

Capacitor C_3 improves the waveform at node G to minimize ripple.

Example: LM341P05 (less heat sink)

$$\begin{aligned} V_O &= 5 \text{ V} & f &= 37 \text{ kHz} & R_2 &= 1 \Omega \\ V_{IN} &= 10 \text{ V} & L &= 500 \mu\text{H} & R_E &= 10 \Omega \\ I_O &= 300 \text{ mA} & t_{on} &= t_{off} & C_2 &= 100 \mu\text{F} \\ & & n &= 80\% & C_3 &= 0.1 \mu\text{F} \\ & & Q &= 2\text{N2905A} & R_1 &= 500 \Omega \\ & & D &= 1\text{N5807} \end{aligned}$$

7.2 NEGATIVE REGULATORS

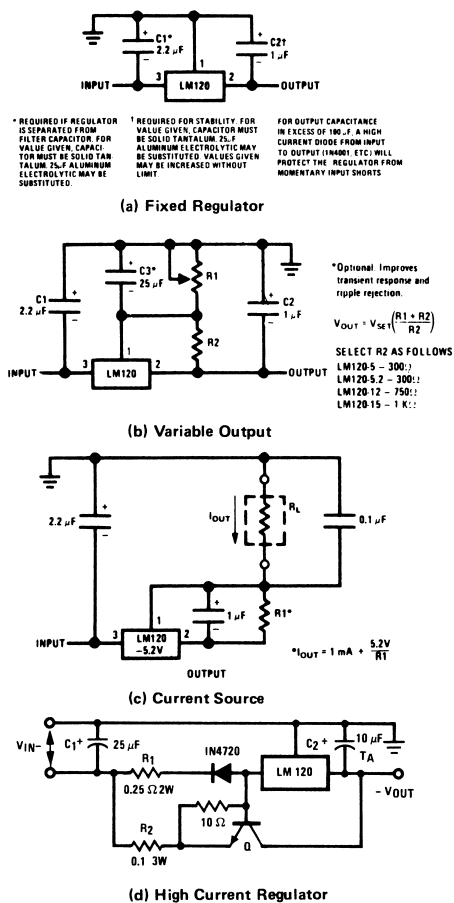


FIGURE 7.14. Negative Regulator Circuits

All the applications circuits for positive regulators can be used with the polarities inverted for the negative regulator LM320/345 series (e.g., reverse the sense of the diodes, replace PNP's with NPN's etc., etc.), as shown in Figure 7.14.

7.2.1 Basic Dual Power Supply

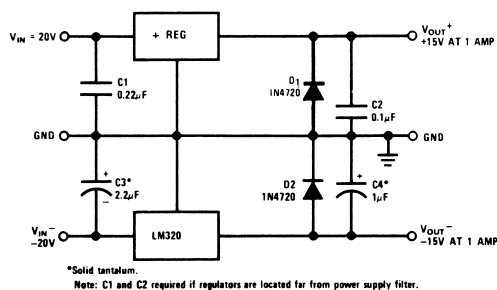


FIGURE 7.15. Dual Power Supply

A positive regulator can be connected with an LM320 to form a non-tracking dual power supply. Each regulator exhibits line and load regulation consistent with their specifications as individual devices. Protective diodes D_1, D_2 allow the regulators to start under common load. They should be rated at the regulator short circuit current.

Examples:

1. $\pm 15 \text{ V}$ supply, 1 A common load:
LM340T-15, LM320T-15, D_1, D_2 : 1N4720.
2. $\pm 12 \text{ V}$ supply, 1 A common load:
LM340T-12, LM320T-12, D_1, D_2 : 1N4720.
3. $\pm 15 \text{ V}$ supply, 200 mA common load:
LM342H-15, LM320H-15, D_1, D_2 : 1N4001.

7.2.2 Trimmed Dual Supply

Figure 7.15 may be modified to obtain a dual supply trimmed to a closer output tolerance. The trimming potentiometers are connected across the outputs so positive or negative trimming currents are available to set the voltage across the $R_1(R_2)$ resistors. R_3, R_5 are included to linearize the adjustment and to prevent shorting the regulator ground pin to opposite polarity output voltages.

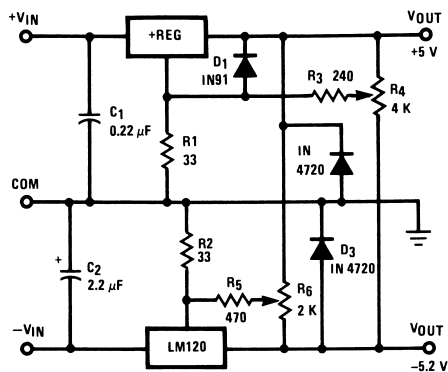


FIGURE 7.16. Trimmed Dual Supply

7.2.3 Tracking Dual Supply

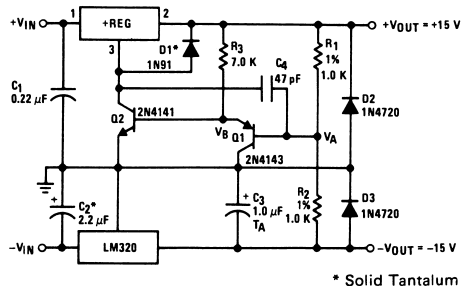


FIGURE 7.17. Tracking Dual Supply

A tracking dual supply can be built as in Figure 7.17 where the positive regulator tracks the negative regulator. V_A is a virtual ground under steady state conditions. Q_2 conducts the quiescent current of the positive regulator.

If $-V_{OUT}$ falls, V_A follows forward biasing collector-base junction of Q_1 . V_B falls, thus raising the collector voltage of Q_2 and $+V_{OUT}$ to restore V_A to desired voltage. Germanium diode D_1 may be needed to start the positive regulator with a high differential load.

Example: ± 15 V, 1 A tracking dual supply:

LM340T-05, LM320T-15.

The 340 will track the LM320 within 100 mV. D_2, D_3 : 1N4720.

7.2.4 Variable Tracking Dual Supply ± 5.0 to ± 18 V @ 1 A

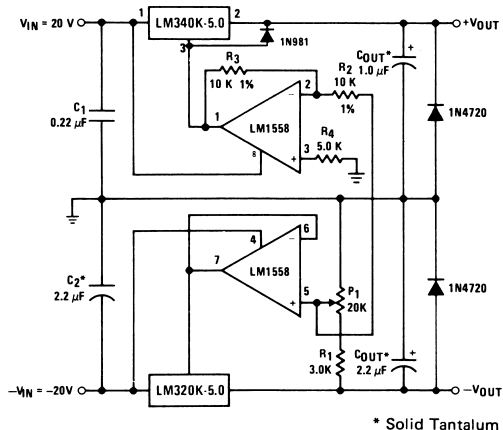
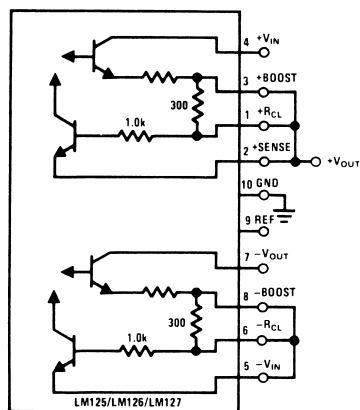


FIGURE 7.18. Variable Tracking Dual Supply ± 5.0 V - ± 18 V

The ground pins of the negative regulator and the positive regulators are controlled by means of a voltage follower and an inverter, respectively. (The same approach is used for the LM340 as in Figure 7.18.) The positive regulator tracks the negative to within 50 mV over the entire output range if R_2 is matched to R_3 within one percent.

7.3 DUAL TRACKING REGULATORS

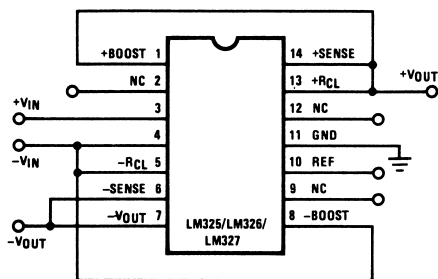


NOTE: PIN NUMBERS FOR METAL CAN PACKAGE ONLY.

(a)

FIGURE 7.19 (a). Basic Dual Regulator

7.3.1 High Current Regulator

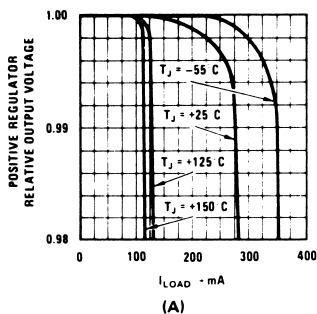


(b)

FIGURE 7.19b. Basic Dual Regulator for the 14-Pin Package*

7.3.1 High Current Regulator

The basic dual regulator is shown connected in Figure 7.19. The only connections required other than plus and minus inputs, outputs, and ground are the completion of the output current paths from $+R_{CL}$ to $+V_{OUT}$ and from $-R_{CL}$ to $-V_{IN}$. These may be direct shorts if the internal preset current limit is desired, or resistors may be used to set the maximum current at some level less than the internal current limit. The internal $300\ \Omega$ resistors from pins 3 to 1 and pins 8 to 6 should be shorted as shown when no external pass transistors are used. To improve line ripple rejection and transient response, filter capacitors may be added to the inputs, outputs, or both, depending on the unregulated input available. If a very low noise output voltage is desired, a capacitor may be connected from the reference voltage pin to ground, thus shunting noise generated by the reference zener. Figure 7.20 shows the internal current-limiting characteristics for the basic regulator circuit of Figure 7.19.



(A)

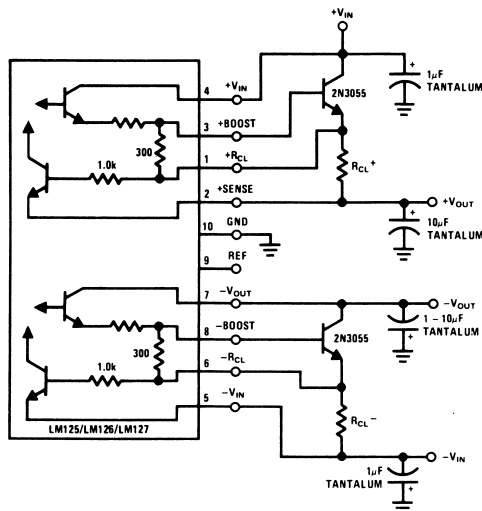
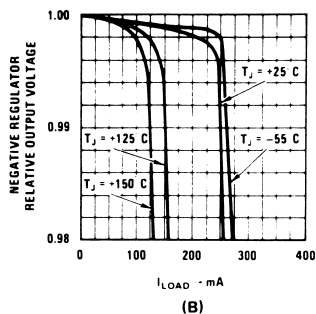


FIGURE 7.21. Boosted High Current Regulator

For applications requiring more output current than can be delivered by the basic regulator, an external NPN pass transistor may be added to each regulator. This will increase the maximum output current by a factor of the external transistor beta. The circuit for current boosted operation is shown in Figure 7.21.

***Note:** In the 14-pin packages (N and S packages) the $-SENSE$ pin (pin 6) has been brought out of the chip, and therefore should be connected to the $-V_O$ pin (pin 7). The remaining applications circuits are shown for the TO-5 package. These circuits also apply for the 14-pin packages provided that the $-V_O$ pin is connected to the $-SENSE$ pin (normally done at the load to eliminate effects of supply line voltage drop).



(B)

FIGURE 7.20. Internal Current Limiting Characteristics

In the boosted mode, current limiting is often a necessary requirement to insure that the external pass device is not overheated or destroyed. Experience shows this to be the usual cause of IC regulator failure. If the regulator output is grounded the pass device may fail and short, destroying the regulator. To limit the maximum output current, a series resistor (R_{CL} in Figure 7.21) is used to sense load current. The regulator will current limit when the voltage drop across R_{CL} equals the current limit sense voltage found in Figure 7.22. Figure 7.23 shows the external current limiting characteristics unboosted and Figure 7.24 shows the external current limiting characteristics in the boosted mode.

To ensure circuit stability at high currents in this configuration, it may be necessary to bypass each input with low inductance, tantalum capacitors to prevent forming resonant circuits with long input leads; $C \geq 1.0\mu F$ is recommended. The same problem can also occur at the regulator output where a $C \geq 10\mu F$ tantalum will ensure stability and increase ripple rejection.

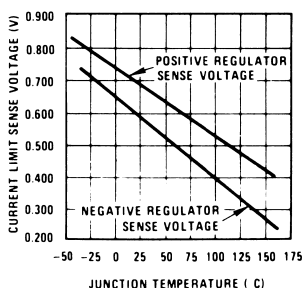


FIGURE 7.22. Current Limit Sense Voltage for a 0.1% Change in Regulated Output Voltage

The 2N3055 pass device is low in cost and maintains a reasonably high beta at collector currents up to several amps. The devices 2N3055 may be of either planar or alloy junction construction. The planar devices, have a high f_T providing more stable operation due to low phase shift. The alloy devices, with f_T typically less than 1.0 MHz, may require additional compensation to guarantee stability. The simplest compensation for the slower devices is the use of output filter capacitor values greater than $50\mu F$ (tantalum). An alternative is to use an RC filter to create a leading phase response to cancel some of the phase lag of the devices. The stability problem with slower pass transistors, if it occurs at all, is usually seen only on the negative regulator. This is because the positive regulator output stage is a

conventional Darlington while the negative output stage contains three devices in a modified triple Darlington connection giving slightly more internal phase shift. Additional compensation may be added to the negative regulator by connecting a small capacitor in the 100 pF range from the negative boost terminal to the internal reference. Since the positive regulator uses the negative regulator output for a reference, this also offers some additional indirect compensation to the positive regulator.

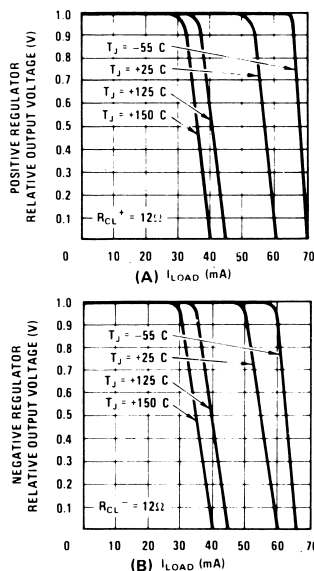


FIGURE 7.23. External Current Limiting Characteristics-Unboosted

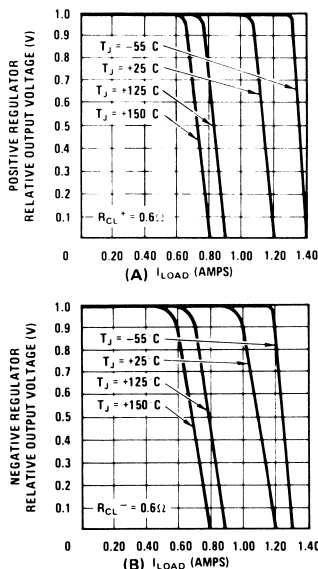


FIGURE 7.24. External Current Limiting Characteristics-Boosted

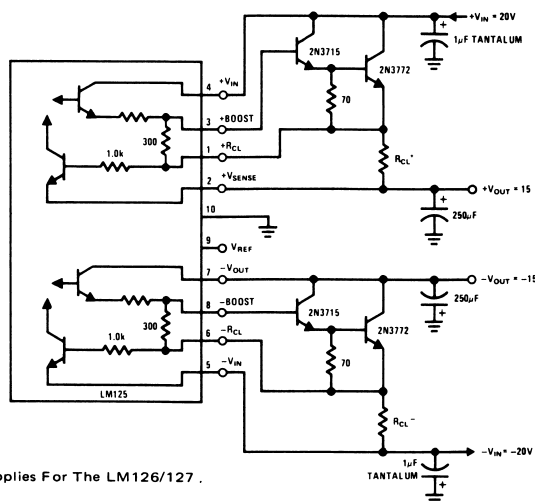
7.3.2 7-Amp Regulator

In Figure 7.25 the single external pass transistor has been replaced by a conventional Darlington using a 2N3715 and a 2N3772. With this configuration the output current can reach values to 10A with very good stability. The external Darlington stage increases the minimum input-output voltage differential to 4.5V. When current limit protection resistor is used, as in Figure 7.25, the maximum output current is limited by power dissipation of the 2N3772 (150W at 25°C). During normal operation this is $(V_{IN} - V_{OUT}) I_{OUT}$ (W), but it increases to $V_{IN} I_{SC}$ (W) under short circuit conditions. The short circuit output current is then:

$$I_{SC} = \frac{P_{MAX} (T_C = 25^\circ C)}{V_{IN}}$$

$$= \frac{150W}{20V (min)} = 7.5A \text{ max.}$$

I_L could be increased to 10A or more only if $I_{SC} < I_L$. A foldback current limit circuit will accomplish this. The typical load regulation is 40 mV from no load to a full load. ($T_j = 25^\circ C$, pulsed load with 20 ms t_{ON} and 250 ms t_{OFF} .)



Note: The Same Circuit Applies For The LM126/127 .

FIGURE 7.25. High Current Regulator Using a Darlington Pair for Pass Elements

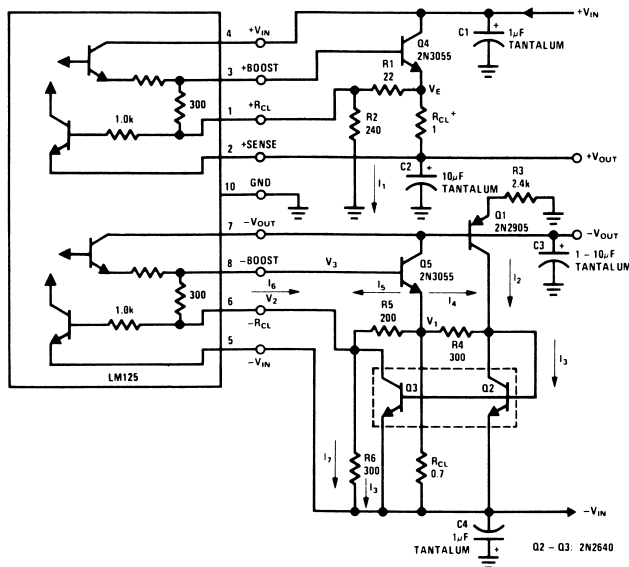
7.3.3 Foldback Current Limiting

In many regulator applications, the normal operation power dissipation in the pass device can easily be multiplied by a factor of ten or more when the output is shorted. This may destroy the pass device, and possibly the regulator, unless the heat sink is oversized to handle this fault condition. A foldback current limiting circuit reduces short circuit output current to a fraction of the full load output current thus avoiding the need for larger heat sink. Figure 7.26 shows a foldback current limiting circuit on both positive and negative regulators.

The foldback current limiting, a fraction of the output voltage must be used to oppose the voltage across the current limit sense resistor. Current limiting does not occur until the voltage across the sense resistor is higher than this opposing voltage by the amount shown in Figure 7.22. When the output is grounded, the opposing voltage is no longer present so current limiting occurs at a lower level. This is accomplished in Figure 7.26 by using a programmable current source to give a

constant voltage drop across R5 for the negative regulator, and by a simple resistor divider for the positive regulator. The reason for the difference between the two is that the negative regulator current limiting circuit is located between the output pass transistor and the unregulated input while the positive regulator current limiter is between the output pass transistor and the regulated output.

The operation of the positive foldback circuit is similar to that described in NSC application note AN-23. A voltage divider R1 and R2 from V_E to ground creates a fixed voltage drop across R1 opposite in polarity to the drop across R_{CL}^+ . When the load current increases to the point where the drop across R_{CL}^+ is equal to the drop across R1 plus the current limit sense voltage given in Figure 7.22, the positive regulator will begin to current limit. As the positive output begins to drop, the voltage across R1 will also decrease so that it now requires less load current to produce the current limit sense voltage. With



Note: For LM126 (127): $V_{IN}^+ = 25$ (20)V, $V_{IN}^- = 25$ V
 $R_1 = 20$ (22), $R_2 = 180$ (80)
 $R_{CL}^+ = 0.9$
 $R_3 = 1.35$ K, $R_6 = 290$; $R_{CL}^- = 0.9$
 $I_{FB} = \pm 2$ A, $I_{SC} = \pm 0.75$ A

FIGURE 7.26. Foldback Current Limiting Circuit

the regulator output fully shorted to ground ($+V_{OUT} = 0$) the current limit will be set by the value of $+R_{CL}$ alone.

$$\text{If } \frac{I_{FB}}{I_{SC}} \leq 5$$

then the following equations can be used for calculating the positive regulator foldback current limiting resistors.

$$R_{CL}^+ \approx \frac{V_{SENSE}}{I_{SC}} \quad (7.16)$$

where V_{SENSE} is from Figure 7.22.

At the maximum load current foldback point:

$$V_{RCL}^+ = I_{FB} R_{CL}^+ \quad (7.17)$$

$$V_{R1} = V_{RCL}^+ - V_{SENSE} \quad (7.18)$$

$$V_{R1} = I_{FB} R_{CL}^+ - V_{SENSE} \quad (7.19)$$

Then

$$R1 = \frac{V_{R1}}{I_1} \quad (7.20)$$

and

$$R2 = \frac{+V_{OUT} + V_{SENSE}}{I_1} \quad (7.21)$$

The only point of caution is to ensure that the total current (I_1) through R2 is much greater than the current contribution from the internal 300Ω resistor. This can be checked by:

$$\frac{I_{FB} R_{CL}^+}{300} \ll I_1 \quad (7.22)$$

Note: The current from the internal 300Ω resistor is $V_{3.1}/300\Omega$, but $V_{3.1} = V_{BE} + V_{RCL} - V_{SENSE}^+$ assuming $V_{BE} \approx V_{SENSE}^+$ at the foldback point, $V_{3.1} \approx V_{RCL}^+ = I_{FB} R_{CL}^+$.

Example:

Design a 2 amp regulator using LM125 and positive foldback current limiting (see Figure 7.26).

Given:

$$I_{FOLDBACK} = 2.0A$$

$$I_{SHORT-CIRCUIT} = 500 \text{ mA}$$

V_{SENSE} (see Figure 7.22).

$$+V_{IN} = 25V$$

$$+V_{OUT} = 15V$$

$$\beta_{PASS \text{ DEVICE}} = 70$$

$$\theta_{JA} = 150^\circ C/W$$

$$T_A = 50^\circ C$$

With a beta of 70 in the pass device and a maximum output current of 2.0A the regulator must deliver:

$$\frac{2A}{\beta} = \frac{2A}{70} = 29 \text{ mA}$$

The LM125 power dissipation will be calculated ignoring any negative output current for this example.

$$\begin{aligned} P_{LM125} &= (V_{IN} - V_{OUT}) I_{OUT} \\ &= (25 - 15) 29 \text{ mA} \\ &= 290 \text{ mW} \end{aligned}$$

$$T_{RISE} @ \theta_{JA} = 150^\circ C/W = 150^\circ C \times 0.29 = 44^\circ C$$

$$T_J = T_A + T_{RISE} = 50^\circ C + 44^\circ C = 94^\circ C$$

From Figure 7.22

$$V_{SENSE} @ (T_J = 94^\circ C) = 520 \text{ mV}$$

From equation (7.17)

$$R_{CL}^+ = \frac{V_{SENSE}}{I_{SC}} = \frac{520 \text{ mV}}{500 \text{ mA}} \cong 1\Omega$$

From equation (7.18)

$$V_{RCL}^+ = I_{FB} R_{CL}^+ = 2A \cdot 1\Omega = 2V$$

From equation (7.19)

$$\begin{aligned} V_{R1} &= V_{RCL}^+ - V_{SENSE} \\ V_{R1} &= 2V - 520 \text{ mV} = 1.480V \end{aligned}$$

A value for I_1 can now be found from equation (7.22)

$$\frac{I_{FB} R_{CL}^+}{300} = \frac{2A \cdot 1\Omega}{300\Omega} = 6.6 \text{ mA}$$

So set $I_1 = 10 \times 6.6 \text{ mA} = 66 \text{ mA}$

From equations (7.20) and (7.21)

$$R1 = \frac{V_{R1}}{I_1} = \frac{1.480V}{66 \text{ mA}} \cong 22\Omega$$

$$R2 = \frac{+V_{OUT} + V_{SENSE}}{I_1} = \frac{15 + 0.520}{66 \text{ mA}} \cong 240\Omega$$

The foldback limiting characteristics are shown in Figure 7.27 for the values calculated above at various operating temperatures.

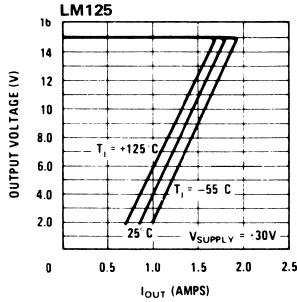


FIGURE 7.27. Positive Regulator Foldback Current Limiting Characteristics

The negative regulator foldback current limiting works essentially the same way as the positive side. Q1 forces a constant current, I_2 , determined by $-V_{OUT}$ and R3, through Q2. Transistors Q2 and Q3 are matched so a current identical to I_3 will flow through Q3. With the output short-circuited ($-V_{OUT} = 0$), Q1 will be OFF, setting $I_2 = 0$. The load current will be limited when V_1 increases sufficiently due to load current to make V_2 higher than $-V_{IN}$ by the current limit sense voltage.

The short circuit current is:

$$I_{SC} \cong \frac{V_{SENSE}}{R_{CL}^-} \quad (7.23)$$

For calculating the maximum full load current with the output still in regulation, current I_2

$$I_2 = \frac{V_{OUT} - V_{BEQ1}}{R3} \quad (7.24)$$

At the point of maximum load current, I_{FB} , where the regulator should start folding back:

$$V_1 = -V_{IN} + I_{FB} R_{CL}^- \quad (7.25)$$

and

$$V_2 = -V_{IN} + V_{SENSE} \quad (7.26)$$

The current through Q2 (and Q3) will have increased from I_2 by the amount of I_4 due

to the voltage V_1 increasing above its no-load quiescent value. Since the voltage across Q2 is simply the diode drop of a base-emitter junction:

$$I_4 = \frac{[V_1 - (-V_{IN})] - V_{BE}}{R4}$$

Substituting in equation (7.25) gives:

$$I_4 = \frac{I_{FB} R_{CL}^- - V_{BE}}{R4} \quad (7.27)$$

$$= \frac{I_{FB} R_{CL}^- - V_{BE}}{300\Omega}$$

The current through Q2 is now

$$I_3 = I_2 + I_4 \quad (7.28)$$

and the current through Q3 is:

$$I_3 = I_5 + I_6 - I_7 \quad (7.29)$$

The drop across R5 is found from:

$$V_1 - V_2 = (-V_{IN} + I_{FB} R_{CL}^-) - [V_{SENSE} + (-V_{IN})];$$

simplifying,

$$V_1 - V_2 = I_{FB} R_{CL}^- - V_{SENSE} \quad (7.30)$$

Since V_{SENSE} is the base to emitter voltage drop of the internal limiter transistor, the V_{SENSE} in equation (7.30) very nearly equals the V_{BE} in equation (7.27). Therefore the drop across R5 approximately equals the drop across R4. The current through R5, I_5 , can now be determined as:

$$I_5 = \frac{I_{FB} R_{CL}^- - V_{SENSE}}{R5} \quad (7.31)$$

Summing the currents through Q3 is now possible assuming the base-emitter drop of the 2N3055 pass device can be given by $V_{BE} \approx V_{SENSE}$:

$$I_6 = \frac{V_3 - V_2}{300} \quad (7.32)$$

where $V_3 = V_1 + V_{BE} \approx V_1 + V_{SENSE}$

$$I_6 = \frac{V_1 + V_{SENSE} - V_2}{300}$$

Substituting in equation (7.30)

$$I_6 = \frac{I_{FB} R_{CL}^-}{300} \quad (7.33)$$

$$I_7 = \frac{V_2 - (-V_{IN})}{R6} = \frac{V_{SENSE}}{R6}$$

Equating equation (7.28) with equation (7.29) and inserting resistor values shown in Figure 7.26,

$$I_2 + I_4 = I_5 + I_6 - I_7$$

$$I_2 + \frac{I_{FB} R_{CL}^- - V_{SENSE}}{300} =$$

$$I_5 + \frac{I_{FB} R_{CL}^-}{300} - \frac{V_{SENSE}}{300} \quad (7.34)$$

Canceling, we find:

$$I_2 = I_5 \quad (7.35)$$

This is the key to the negative foldback circuit. Current source Q1 forces current I_2 to flow through resistor R5. The voltage drop across R5 opposes the normal current limit sense voltage so that the regulator will not current limit until the drop across R_{CL}^- due to load current, equals the controlled drop across R5 plus V_{SENSE} (given in Figure 7.22). This can be written as:

$$I_{FB} = \frac{V_{SENSE} + I_2 R_5}{R_{CL}^-}$$

$$I_{FB} = \frac{V_{SENSE} + 200 I_2}{R_{CL}^-} \quad (7.36)$$

Example:

Given:

$$I_{FOLDBACK} = 2.5A$$

$$I_{SHORT-CIRCUIT} = 750 \text{ mA}$$

$$V_{SENSE} \text{ (See Figure 7.22)}$$

$$-V_{IN} = 25V$$

$$-V_{OUT} = -15V$$

$$\beta_{PASS \text{ DEVICE}} = 90$$

$$\theta_{JA} = 150^\circ C/W$$

$$T_A = 25^\circ C$$

The same calculations are used here to figure V_{SENSE} as with the positive regulator foldback example maximum regulator output current is calculated from:

$$I_{OUT} = \frac{2.5 \text{ A}}{90} = 28 \text{ mA}$$

$$P_{LM125} = (V_{IN} - V_O) I_{OUT}$$

$$= 10V \times 28 \text{ mA}$$

$$= 280 \text{ mW}$$

$$T_{RISE} = 150^\circ C/W \times 0.28W = 42^\circ C$$

$$T_J = T_A + T_{RISE} = 25^\circ C + 42^\circ C = 67^\circ C$$

From Figure 7.22:

$$V_{SENSE} = 500 \text{ mV}$$

From equation (7.23):

$$R_{CL}^- = \frac{500 \text{ mV}}{750 \text{ mA}} = 0.68\Omega$$

From equation (7.36):

$$I_2 = \frac{I_{FB} R_{CL}^- - V_{SENSE}}{200\Omega} = 6.0 \text{ mA}$$

From equation (7.24):

$$R_3 = \frac{V_{OUT} - V_{BEQ1}}{I_2}$$

$$R_3 \approx \frac{14.3}{6.0 \text{ mA}} = 2.4k$$

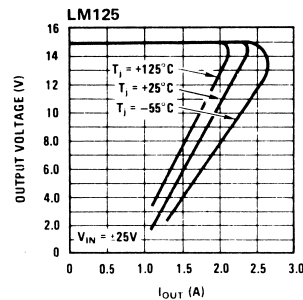


FIGURE 7.28. Negative Regulator Foldback Current Limiting Characteristics

Figure 7.27 and 7.28 show the measured foldback characteristics for the values derived in the design examples. The value of R5 is set low so that the magnitude of I_5 for foldback is greater than I_4 through I_6 . This reduces the foldback point sensitivity to the TC of the internal 300Ω resistor and any mismatch in the TC of Q2, Q3 or the pass device.

R6 can be computed from equation (7.33):

$$R_6 = \frac{V_{SENSE}^-}{I_7} = \frac{V_{SENSE}^-}{I_5 + I_6 - I_3}$$

combining (7.28) and (7.35).

$$R6 = \frac{V_{SENSE}}{I_6 - I_4} = \frac{V_{SENSE}}{I_{FB} R_{CL} \left(\frac{1}{300} - \frac{1}{R4} \right) + \frac{V_{BE}}{R4}} \quad (7.37)$$

Setting $V_{BE} \approx V_{SENSE}$ and $R4 = 300$ to match the internal 300Ω (22) becomes:

$$R6 = R4$$

$$\text{Also setting } \frac{I_4}{I_5} = \frac{2}{3} \rightarrow R5 = 200$$

7.3.4 A 10-Amp Regulator

Figure 7.29 illustrates the complete schematic of a 10A regulator with foldback current limiting. The design approach is similar to that of the 2A regulator. However, in this design, the current contribution from the internal 300Ω resistor is greater due to the $2V_{BE}$ drop across the Darlington pair. Expression (7.22) becomes:

$$\frac{I_{FB} R_{CL} + V_{BE}}{300} \ll I_1; \quad (7.38)$$

and, for the negative regulator, expression (7.39) becomes:

$$R6 = \frac{V_{SENSE}}{I_{FB} R_{CL} \left(\frac{1}{300} - \frac{1}{R4} \right) + V_{BE} \left(\frac{1}{300} + \frac{1}{R4} \right)} \quad (7.40)$$

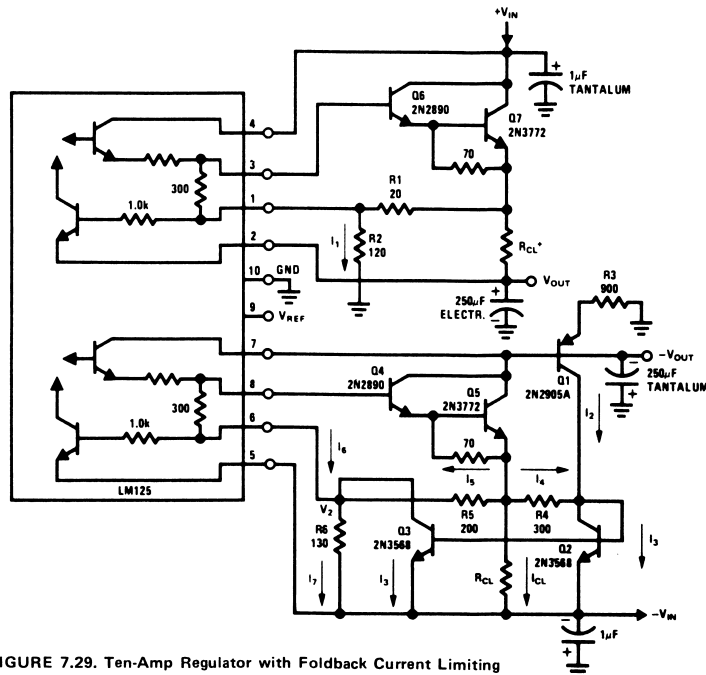


FIGURE 7.29. Ten-Amp Regulator with Foldback Current Limiting

The disagreement between the theoretical and experimental values for the negative regulator is not alarming. In fact R_{CL} was based on equation (7.23), which is correct if for zero V_{OUT} , I_5 is zero as well. This implies:

$$V_{SENSE} \text{ (at SC)} = \frac{V_{BEQ4} + V_{BEQ5}}{2} \text{ (at SC)}$$

which is a first order approximation.

Figure 7.30 illustrates the power dissipation in the external power transistor for both sides. Maximum power dissipation occurs between full load and short circuit so the heat sink for the 2N3772 must be designed accordingly, remembering that

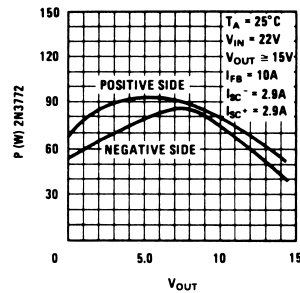


FIGURE 7.30. Power Dissipation in the External Pass Transistor (Q5, Q7)

the 2N3772 must be derated according to $0.86W/^{\circ}C$ above $25^{\circ}C$. This corresponds to a thermal resistance junction to case of $1.17^{\circ}C/W$.

Example

Positive Side	Theoretical Value	Experimental Results
$I_{FB} = 10 \text{ A}$	$I_{125} = 13 \text{ mA}$	$I_{FB} = 9.8 \text{ A}$
$I_{SC} = 2.5 \text{ A}$	$P_{LM125} = 150 \text{ mW}$	$I_{SC} = 2.9 \text{ A}$
$V_{IN} = 22 \text{ V}$	$R_{CL}^+ = 0.26 \Omega$	$R_{CL}^+ = 0.26 \Omega$
$V_{OUT} = 15 \text{ V}$	$R1 = 21 \Omega$	$R1$: adjusted to 20Ω
$\beta = \beta1 \beta2 = 15 \times 50 = 750 \text{ min}$	$R2 = 130 \Omega$	$R2$: adjusted to 120Ω
$T_A = 25^\circ \text{C}$	$V_{SENSE}^+ = 650 \text{ mV}$	

Negative Side	Theoretical Value	Experimental Results
$I_{FB} = 10 \text{ A}$	$R_{CL}^- = 0.22 \Omega$	$I_{FB} = 10 \text{ A}$
$I_{SC} = 2.5 \text{ A}$	$R4 = 300 \Omega$	$I_{SC} = 2.9 \text{ A}$
$V_{IN} = 22 \text{ V}$	$R5 = 200 \Omega$	R_{CL}^- : adjusted to 0.3Ω
$V_{OUT} = 15 \text{ V}$	$R6 = 150 \Omega$	$R6$: adjusted to 130Ω
$\beta = 800$	$R3 = 1.6 \text{ k}\Omega$	$R3$: adjusted to 900Ω
$T_A = 25^\circ$	$V_{SENSE}^- = 550 \text{ mV}$	
$\frac{I_4}{I_5} = \frac{2}{3}$		

Note: For this example, in designing each side, the power dissipation of the opposite side has not been taken into the account.

7.3.5 Positive Current Dependent Simultaneous Current Limiting

The LM125/LM126/LM127 uses the negative output as a reference for the positive regulator. As a consequence, whenever the negative output current limits, the positive output follows tracks to within 200 – 800 mV of ground. If, however, the positive regulator should current limit the negative output will remain in full regulation. This imbalance in output voltages could be a problem in some supply applications.

As a solution to this problem, a simultaneous limiting scheme, dependent on the positive regulator output current, is presented in Figure 7.31. The output current causes an I-R drop across R1 which brings transistor Q1 into conduction. As the positive load current increases I_1 increases until the voltage drop across R2 equals the negative current limit sense voltage. The negative regulator will then current limit, and positive side will closely follow the negative output down to a level of 700 – 800 mV. For V_{OUT}^+ to drop the final 700 – 800 mV with small output current change, R_{CL}^+ should be adjusted so that the positive current limit is slightly larger than the simultaneous limiting. Figure 7.32 illustrates the simultaneous current limiting of both sides.

The following design equations may be used:

$$R1 I_{CL}^+ = R3 I_1 + V_{BEQ1} \quad (7.41)$$

$$I_1 = \frac{V_{SENSE}^-}{R2} \quad (7.42)$$

Combining (7.41) and (7.42)

$$I_{CL}^+ = \frac{\frac{R3}{R2} V_{SENSE}^- + V_{BEQ1}}{R1} \quad (7.43)$$

with

$$R_{CL}^+ = \frac{V_{SENSE}^+}{1.1 I_{CL}^+} \quad (7.44)$$

The negative current limit (independent of I_{CL}^+) can be set at any desired level.

$$I_{CL}^- = \frac{V_{SENSE}^- + V_{DIODE}}{R_{CL}^-} \quad (7.45)$$

Transistor Q2 turns off the negative pass transistor during simultaneous current limiting.

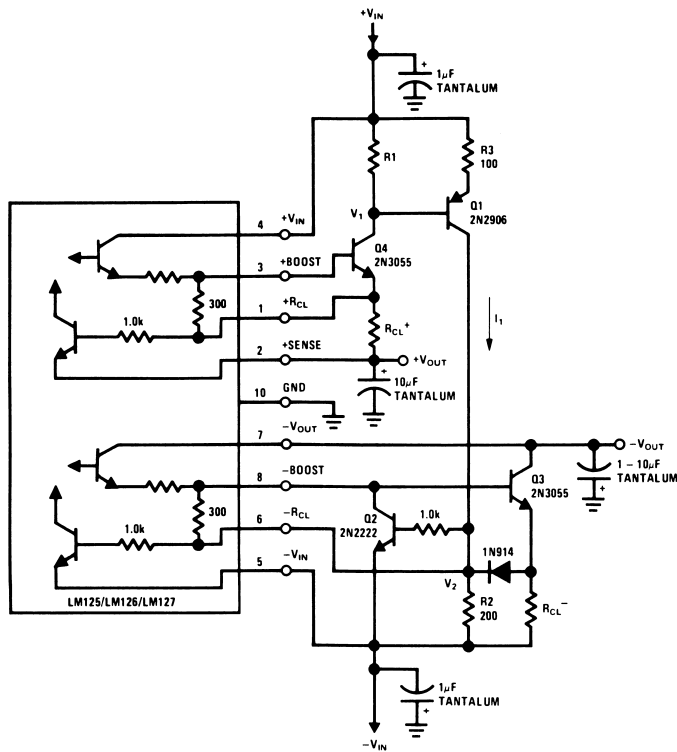


FIGURE 7.31. Positive Current Dependent Simultaneous Current Limiting

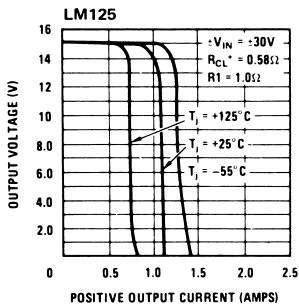


FIGURE 7.32. Positive Current Dependent Simultaneous Shutdown

7.3.6 Electronic Shutdown

In some regulated supply applications it is desirable to shutdown the regulated outputs ($\pm V_O = 0$) without having to shutdown the unregulated inputs (which may be powering additional equipment). Various shutdown methods may be used. The simplest is to insert a relay, a saturated bipolar device, or some other type switch in series with either the regulator inputs or outputs. The switch must be able to open and close under maximum load current which may be several amps.

As an alternate solution, the internal reference voltage of the regulator may be shorted to ground. (See Figure 7.37)

This will force the positive and negative outputs to approximately +700 mV and +300 mV respectively. Both outputs are fully active so the full output current can still be supplied into a low impedance load. If this is unacceptable, another solution must be found.

The circuit in Figure 7.33 provides complete electronic shutdown of both regulators. The shutdown control signal is TTL compatible but by adjusting R8 and R9 the regulator may be shutdown at any desired level above $2 V_{BE}$, calculated as follows:

$$V_T \approx \left[\frac{R8}{R3 \beta Q4} + \frac{R9}{R3} \right] V_{BE} + 2 V_{BE} \quad (7.46)$$

Positive and negative shutdown operations are similar. When a shutdown signal V_T is applied, Q4 draws current through R3 and D2 establishing a voltage V_R which starts the current sources Q1 and Q2. Assuming that Q1 and Q2 are matched, and making $R1 = R2 = R3$, the currents I_1, I_2, I_3 are equal and both sides of the regulator shutdown simultaneously.

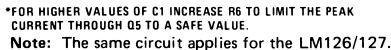


Figure 7.34 the diode D1 in Figure 7.33 may be omitted. The shutdown characteristics of Figure 7.33 are shown in Figure 7.34.

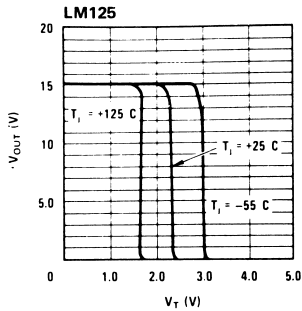
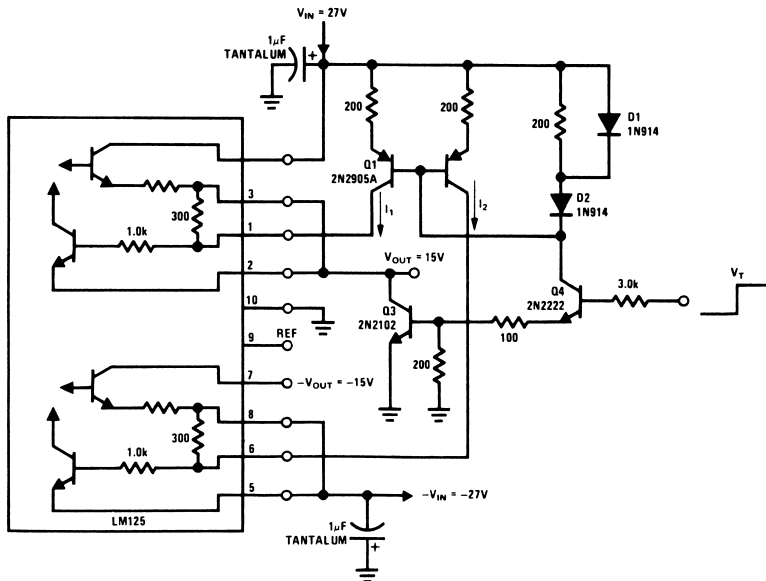


FIGURE 7.35. Electronic Shutdown Characteristics

The normal current limiting current is set by equation (7.47)

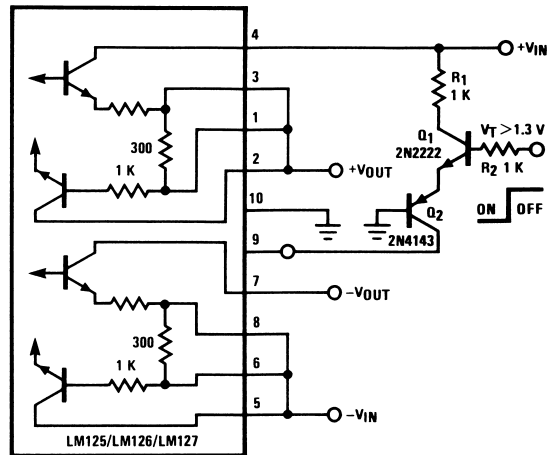
$$I_{CL} = \frac{V_{SENSE} + V_{DIODE}}{R_{CL}} \quad (7.47)$$

The same approach is used with the unboosted regulator shown in Figure 7.36. In this case the voltage sense resistor is the internal 300Ω one. Since output capacitors are no longer required Q3 is just used as a current sink and its emitter load has been removed.



Note: The Same Circuit Applies For The LM126/127.

FIGURE 7.36. Electronic Shutdown for the Basic Regulator



NOTE: PIN NUMBERS FOR METAL CAN PACKAGE ONLY
FIGURE 7.37. Simplified Shutdown

7.3.7 Power Dissipation

The power dissipation of the LM125 is:

$$P_d = (V_{IN}^+ - V_{OUT}^+) I_{OUT}^+ + (V_{IN}^- - V_{OUT}^-) I_{OUT}^- + V_{IN}^+ I_S^+ + V_{IN}^- I_S^-$$

where I_S is the standby current.

Example:

±1A regulator using 2N3055 pass transistors. Assuming a $\beta = 100$, and ±25V supply,

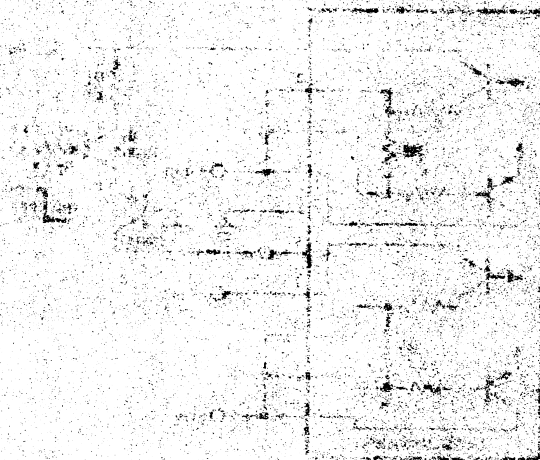
$$P_d = 400 \text{ mW.}$$

The temperature rise for the TO-5 package will be:

$$T_{RISE} = 0.4 \times 150^\circ\text{C/W} = 60^\circ\text{C}$$

Therefore the maximum ambient temperature is $T_{AMAX} = T_{JMAX} - T_{RISE} = 90^\circ\text{C}$. If the device is to operate at T_A above 90°C then the TO-5 package must have a heat sink. T_{RISE} in this case will be:

$$T_{RISE} = P_d (\theta_{J-C} + \theta_{C-S} + \theta_{S-A}).$$



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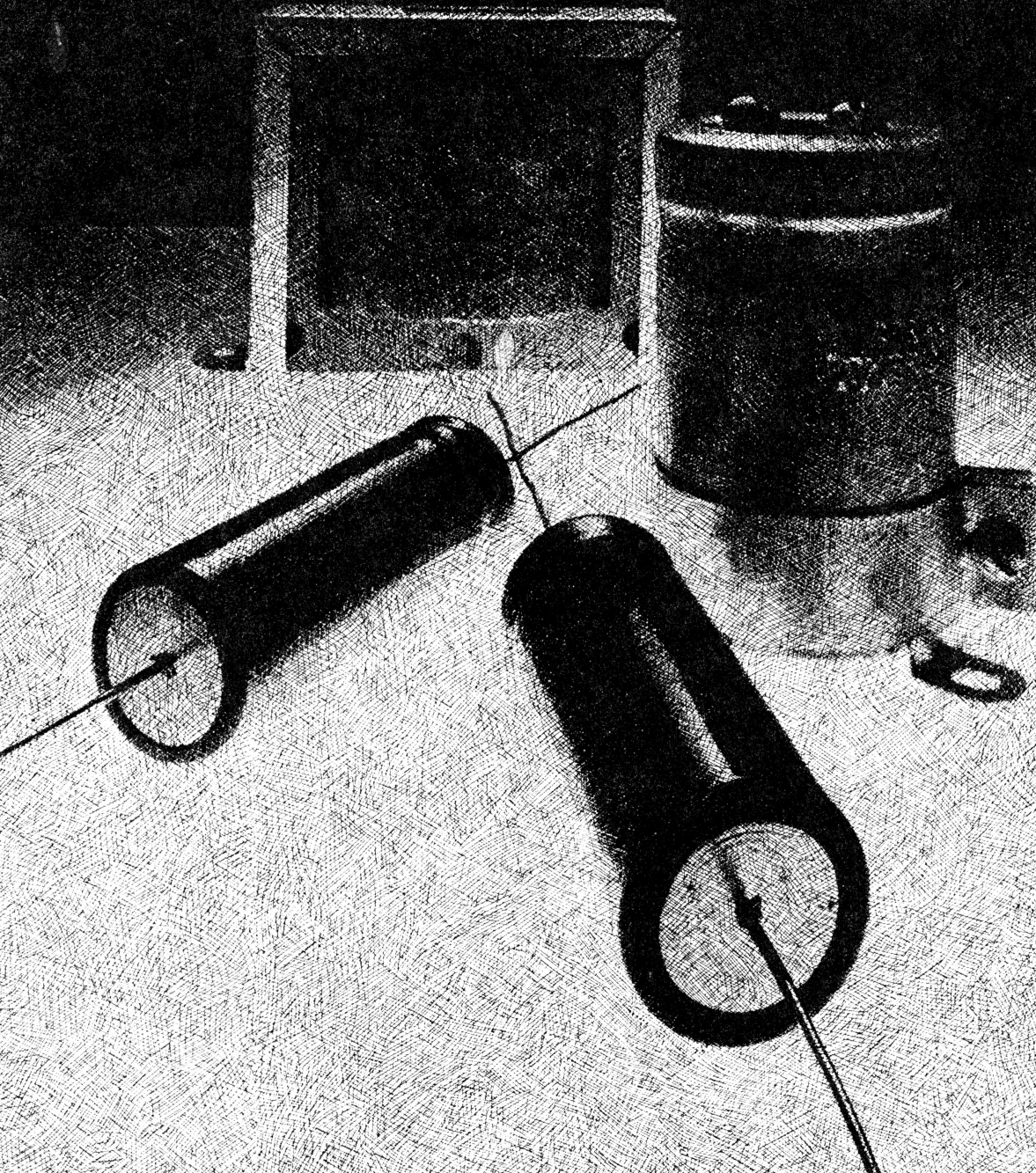
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Section 8.0

Power Supply Design



8.0 POWER SUPPLY DESIGN

8.1 GENERAL

This section presents supply and filter design methods and aids for half-wave, full-wave center tap, and bridge rectifier power supplies. The treatment is sufficiently detailed to allow even those unfamiliar with power supply design to specify filters, rectifier diodes and transformers for single-phase supplies. A general treatment referring to Figure 8.1 is given, followed by a design example. No attempt is made to cover multi-phase circuits or voltage multipliers.

8.2 LOAD REQUIREMENTS

The voltage, current, and ripple requirements of the load must be fully described prior to filter and supply design. Actually, so far as the filter and supply are concerned, the load requirements are those at the regulator input (see Figure 8.1). Therefore V_{IN} and I_{IN} become the governing conditions, where:

$I_{IN} = I_O + I_Q$, output current plus regulator quiescent current

$I_{IN(MAX)} \approx I_{O(MAX)}$, full-load operating current

$I_{IN(MIN)} \leq I_Q$, no-load or minimum operating current; could be near zero

$V_{IN(PK)} = V_M$, maximum permissible instantaneous no-load filter output voltage equal to peak value of transformer secondary voltage at highest design line voltage V_{PRI} ; limited by absolute maximum regulator input voltage listed in Table 2.1 as "Max V_{IN} "

$V_{IN} > V_O$, nominal DC voltage input to the regulator, usually 2 to 15 V higher than V_O

$V_{IN(MIN)} \approx V_O + 2V$, minimum instantaneous full-load filter output voltage including ripple voltage; limited by minimum regulator input voltage to insure satisfactory regulation ($V_O + V_{dropout}$) or minimum regulator input voltage to allow regulator start-up under full load or upon removal of a load short circuit.

r_f

rms ripple factor at filter output expressed as a percentage of V_{IN} ; limited by maximum permissible ripple at load as modified by the ripple rejection characteristics of the regulator

8.3 FILTER SELECTION, CAPACITOR OR INDUCTOR-INPUT

For power supplies using voltage regulators, the filter will most often use capacitor input, therefore emphasis will be placed upon that type of filter in following discussions. Notable differences between the two types of filters are that the capacitor input filter exhibits:

- Higher DC output voltage
- Poorer output voltage regulation with load variation
- Higher peak to average diode forward currents
- Lower diode PIV rating requirements
- Very high diode surge current at turn-on
- Higher peak to average transformer currents

The voltage regulator overcomes disadvantage (b) while semiconductor diodes of moderate price meet most of the peak and surge requirements except in supplies handling many amperes. Still, it may be necessary to balance increased diode and transformer cost against the alternative of a choke-input filter. In power supply designs employing voltage regulators, it is assumed that only moderate filter output regulation and ripple are required. Therefore, a capacitor input filter would exhibit peak currents considerably lower than indicated in the comparison of Table 8.1.

8.4 FILTER DESIGN, CAPACITOR INPUT

Figure 8.2 shows a full-wave, capacitor-input (filter) rectifier system with typical voltage and current waveforms. Note that ripple is inevitable as the capacitor discharges approximately linearly between voltage peaks. Figure 8.3 shows the effects on DC voltage, ripple, and peak diode current under varying conditions of load resistance, input capacitance, series diode and transformer resistance R_S , and transformer leakage inductance. The most practical design procedure for capacitor-input filters is to use the graphs of Figures 8.4 to 8.7. Note, however, that these include the effects of diode dynamic

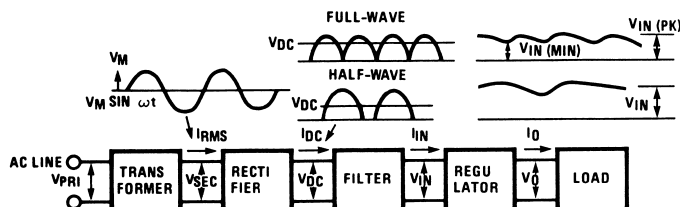
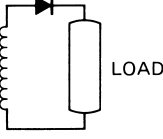
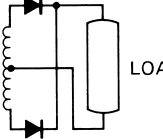
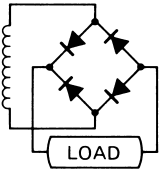
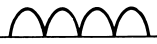


FIGURE 8.1. Power Supply Block Diagram, General Case

Table 8.1 Summary of Significant Rectifier Circuit Characteristics
 Single Phase Circuits
 Capacitive Data is for $\omega CR_L = 100$ & $R_S/R_L = 2\%$ (higher values)
 and for $\omega CR_L = 10$ & $R_S/R_L = 10\%$ (lower values)

Rectifier Circuit Connection	Single Phase Full Wave Center Tap			Single Phase Half Wave			Single Phase Full Wave Bridge		
									
Voltage Waveshape to Load of Filter									
CHARACTERISTIC LOAD	R	L	C	R	L	C	R	L	C
Average Diode Current $I_F(\text{AVG})/I_O(\text{DC})$	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5
Peak Diode Current $I_{FM}/I_F(\text{AVG})$	3.14	-	8 5.2	3.14	2	10 6.2	3.14	2	10 6.2
Diode Current Form Factor, $F = I_F(\text{RMS})/I_F(\text{AVG})$	1.57	-	2.7 2	1.57	1.41	3 2.2	1.57	1.41	3 2.2
RMS Diode Current $I_F(\text{RMS})/I_O(\text{DC})$	1.57	-	2.7 2	0.785	0.707	1.35 1.1	0.785	0.707	1.35 1.1
RMS Input Voltage per Transformer Leg $V_{\text{SEC}}/V_{\text{IN}}(\text{DC})$	2.22	2.22	0.707	1.11	1.11	0.707	1.11	1.11	0.707
Transformer Primary VA Rating V_A/P_{DC}	3.49	-	-	1.23	1.11	-	1.23	1.11	-
Transformer Secondary VA Rating V_A/P_{DC}	3.49	-	-	1.75	1.57	-	1.23	1.11	-
Total RMS Ripple %	121	-	-	48.2	-	-	48.2	-	-
Rectification Ratio (Conversion Efficiency) %	40.6	-	-	81.2	100	-	81.2	100	-

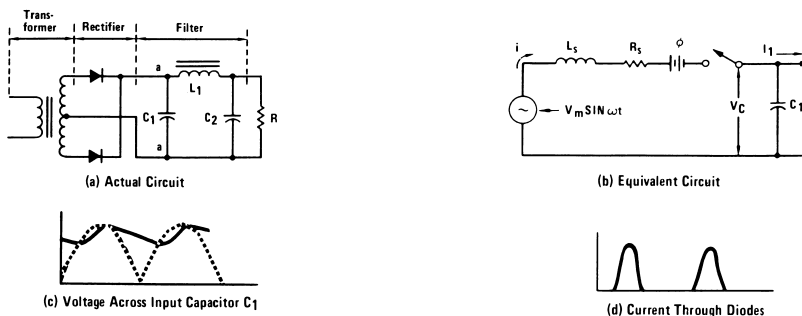


FIGURE 8.2. Actual and Equivalent Circuits of Capacitor-Input Rectifier System, Together with Oscillograms of Voltage and Current for a Typical Operating Condition

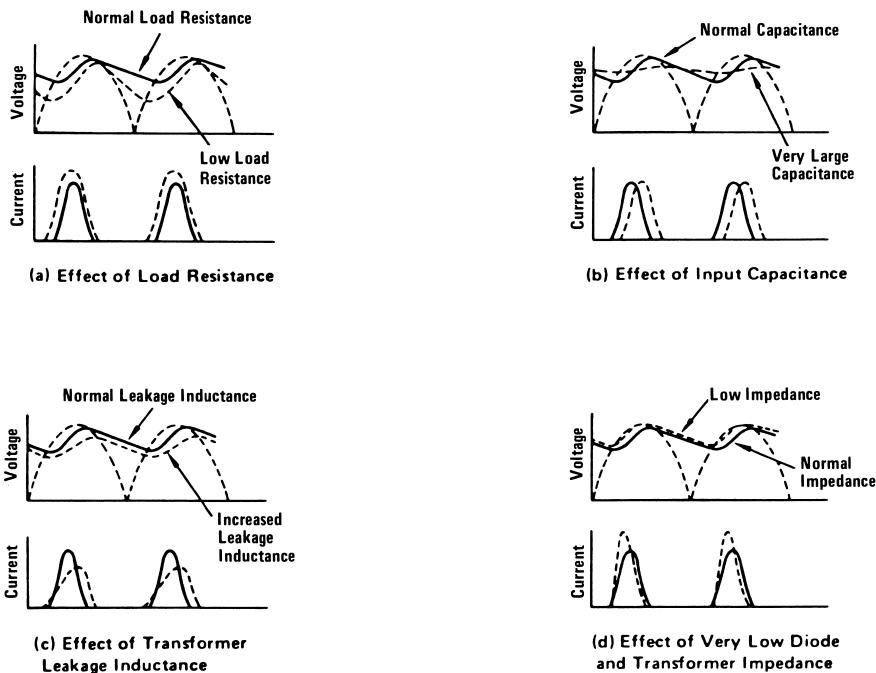


FIGURE 8.3. Effects of Circuit Constants and Operating Conditions on Behavior of Rectifier Operated with Capacitor-Input Filter

resistance within R_S . Diode forward drop is not included, and must be subtracted from the transformer secondary voltage. A good rule of thumb is to subtract 0.7 V from the transformer voltage and assume diode dynamic resistance is insignificant (0.02Ω at $I_F = 1 \text{ A}$, 0.26Ω at $I_F = 100 \text{ mA}$); ordinarily the transformer resistance will overshadow diode dynamic resistance.

Figures 8.4 and 8.5 show the relationship between peak AC input voltage and DC output voltage as a relation to load resistance R_L , series circuit resistance R_S , and filter input capacitance C . Figure 8.4 is for half-wave rectifiers and Figure 8.5 is for full-wave rectifiers. Note that the horizontal axis is labeled in units of ωCR_L where:

ω = AC line frequency in Hertz $\times 2\pi$

C = value of input capacitor in Farads

$R_L = V_{IN}/I_{IN} \approx V_O/I_O$, equivalent load resistance in Ohms

R_S = total of diode dynamic resistance, transformer secondary resistance, reflected transformer primary resistance, and any added series surge limiting resistance

voltage regulation with low ripple and achieving low cost. Referring to Figures 8.4 and 8.5:

- Good regulation means $\omega CR_L \approx 10$
- Low ripple may mean $\omega CR_L > 40$
- High efficiency means $R_S/R_L < 0.02$
- Low cost usually means low surge currents and small C
- Good transformer utilization means low VA ratings, best with full-wave bridge FWB circuit, followed by full-wave center tap FWCT circuit.

In most cases, a minimum capacitance accomplishing a reasonable full-load to no-load regulation is preferable for low cost. To achieve this, use an intercept with the upper knee of the curves in Figures 8.4 and 8.5. Occasionally, a minimum value filter capacitor will not result in a lower cost system. For example, increasing the value of C may allow higher R_S/R_L to result in lower surge and RMS currents, thus allowing lower cost transformers and diodes. Be sure that capacitors used have adequate ripple current ratings.

Design procedure is as follows:

- Assuming that V_O , I_O , ω , and load ripple factor r_f have been established and an appropriate voltage

The major design trade-off encountered in designing capacitor-input filters is that between achieving good

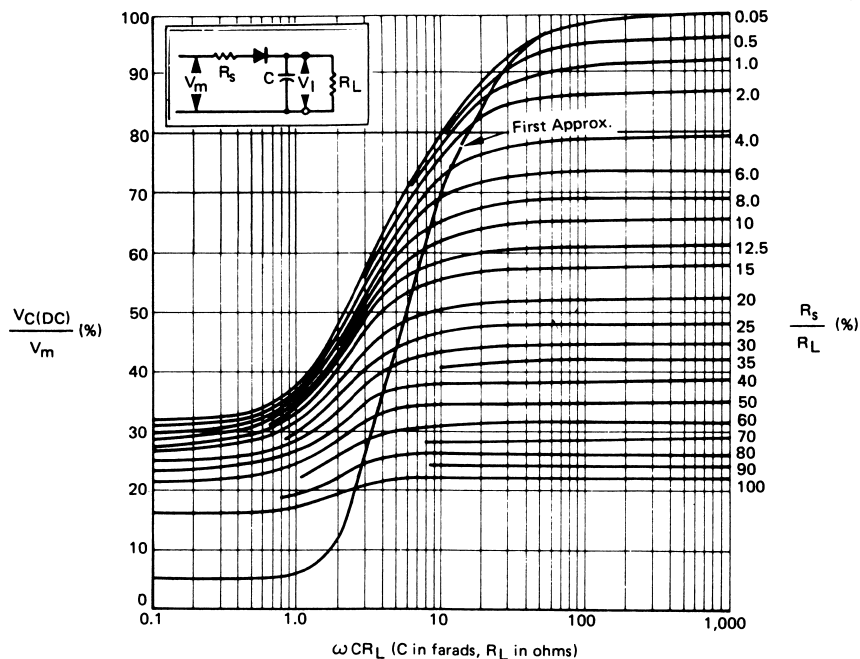


FIGURE 8.4. Relation of Applied Alternating Peak Voltage to Direct Output Voltage in Half-Wave Capacitor-Input Circuits. (From O. H. Schade, Proc. IRE, vol. 31, p. 356, 1943.)

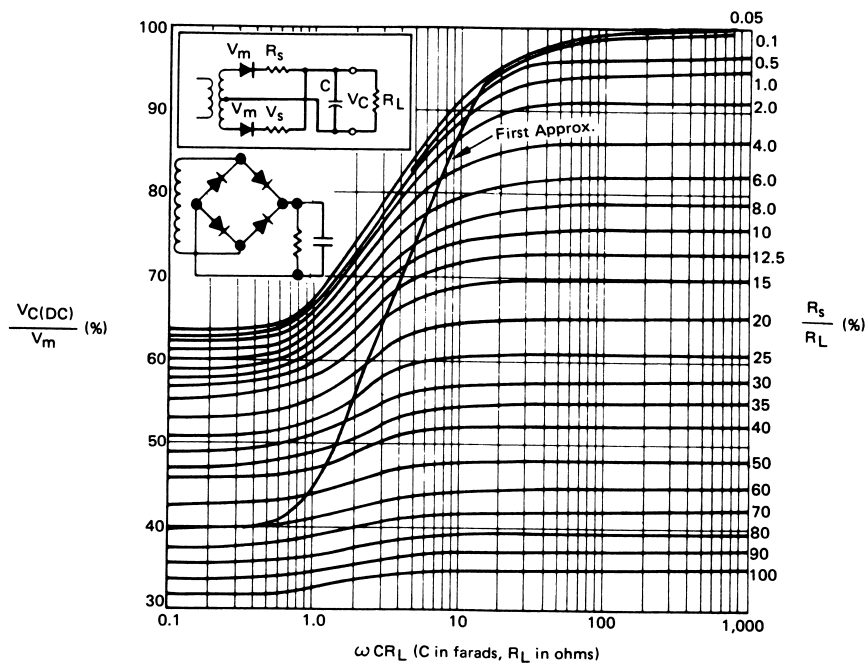


FIGURE 8.5. Relation of Applied Alternating Peak Voltage to Direct Output Voltage in Full-Wave Capacitor-Input Circuits. (From O. H. Schade, Proc. IRE, vol. 31, p. 356, 1943.)

regulator has been selected, we know or can determine

$$\omega = 2\pi f = 377$$

$$\omega = 2\pi f = 377 \text{ rad/sec for 60 Hz line}$$

$r_f(\text{in}) = r_f(\text{out}) \times \text{ripple reduction factor of selected regulator}$

$V_{IN(PK)} \leq \text{Max } V_{IN}$ for the selected regulator; allow for highest line voltage likely to be encountered

$I_{IN(MIN)} \approx V_O + 2 \text{ V}$; allow for lowest line voltage

$V_{IN(DC)}^+ = V_{IN}$, usually 2-15 V above V_O ; if chosen midway between $V_{IN(PK)}$ and $V_{IN(MIN)}$ or slightly below that point, will allow for greatest ripple voltage

$I_{IN} \approx I_O$ for full load

$I_{IN(MIN)} = I_O$ for open load

$$R_L = V_{IN(DC)} / I_{IN}$$

$$R_{L(MIN)} = V_{IN(MIN)} / I_{IN}$$

- b) Set $V_M \leq V_{IN(PK)}$ and calculate $V_{IN(DC)} / V_{IN}$. Enter the graph of Figure 8.4 or 8.5 at the calculated $V_{IN(DC)} / V_M$ to intercept one of the $R_S / R_L = \text{constant}$ lines. Either estimate R_S at this time or intercept the curve marked "First Approximation."

- c) Drop vertically from the intercept of step (b) to the horizontal axis and read $\omega C R_L$. Calculate C, allowing for usual commercial tolerance on capacitors of +100, -50%.

If $V_{IN(DC)}$ is midway between $V_{IN(PK)}$ and $V_{IN(MIN)}$, the supply can present maximum ripple to the regulator. A low value of C is then practical. If $V_{IN(DC)}$ is near $V_{IN(MIN)}$, regulator power dissipation is low and supply efficiency is high; however ripple must be low, requiring large C.

- d) Determine ripple factor r_f from Figure 8.6. Make certain that the ripple voltage does not drop instantaneous V_{IN} below $V_{IN(MIN)}$.

The ripple factor could determine minimum required C if ripple is the limiting factor instead of voltage regulation. Again, allow for -50% tolerance on the capacitor.

$$V_{\text{ripple(pk)}} = \sqrt{2} \frac{r_f}{100} V_{IN(DC)}$$

8.5 DIODE SPECIFICATION

Find diode requirements as follows:

- a) $I_{F(AVG)} = I_{IN(DC)}$ for half-wave rectification
 $= I_{IN(DC)} / 2$ for full-wave rectification
- b) Determine peak diode current ratio from Figure 8.7; remember to allow for highest operating line voltage and +100% capacitor tolerance
- $I_{FM} = I_{FM} / I_{F(AVG)} \times I_{IN(DC)}$ for half-wave
 $= I_{FM} / I_{F(AVG)} \times I_{IN(DC)} / 2$ for full-wave

- c) Determine diode surge current requirement at turn-on of a fully discharged supply when connected at the peak of the highest expected AC line waveform. Surge current is

$$I_{\text{SURGE}} = E_M / (R_S + \text{ESR})$$

where ESR = effective series resistance of capacitor.

- d) Find required diode PIV rating from Figure 8.8. Actually, required PIV may be considerably more than the value thus obtained due to noise spikes on the line. See Section 8.7 for details on transient protection. Remember that the PIV for the diodes in the FWB configuration are one-half that of diodes as found in FWCT or HW rectifier circuits.

The diodes may now be selected from diode manufacturers' data sheets. If calculated surge current rating or peak current ratings are impractically high, return to step 8.4 (b) and choose a higher R_S / R_L or lower C. Conversely, it may be practical to choose lower R_S / R_L or higher C if diode current ratings can be practically increased without adverse effect on transformer cost; the result will be higher supply efficiency.

8.6 TRANSFORMER SPECIFICATION

A decision may have been made at step 8.4 (b) as to using half-wave or full-wave rectification. The half-wave circuit is often all that is required for low current regulated supplies; it is rarely used at currents over 1 A as large capacitors and/or high surge currents are dictated. Transformer utilization is also quite low, meaning that higher VA rating is required of the transformer in HW circuits than in FW circuits (see VA ratings of Table 8.1).

Half-wave circuits are characterized by low $V_{IN(DC)} / V_M$ ratio, or very large C required (about 4 times that required for FW circuits; high ripple; high peak to average diode and transformer current ratios; and poor transformer utilization. They do, however, require only one diode.

Full-wave circuits are characterized by high $V_{IN(DC)} / V_M$ ratio, low C value required, low ripple, low peak to average diode and transformer current ratios, and good transformer utilization. They do require two diodes in the center-tap version, while the bridge configuration with its very high transformer utilization requires four diodes.

The information necessary to specify the transformer is:

- a) Half-wave, full-wave CT or full-wave bridge circuit
- b) Secondary V_{RMS} per transformer leg,
 $[V_M + (0.7)^*] / \sqrt{2}$ from Section 9.4
- c) Total equivalent secondary resistance including reflected primary resistance from Section 8.4
- d) Peak, average, and RMS diode or winding currents from Sections 8.5 (a) and (b), and VA ratings

* (1.4) For full-wave bridge circuit.

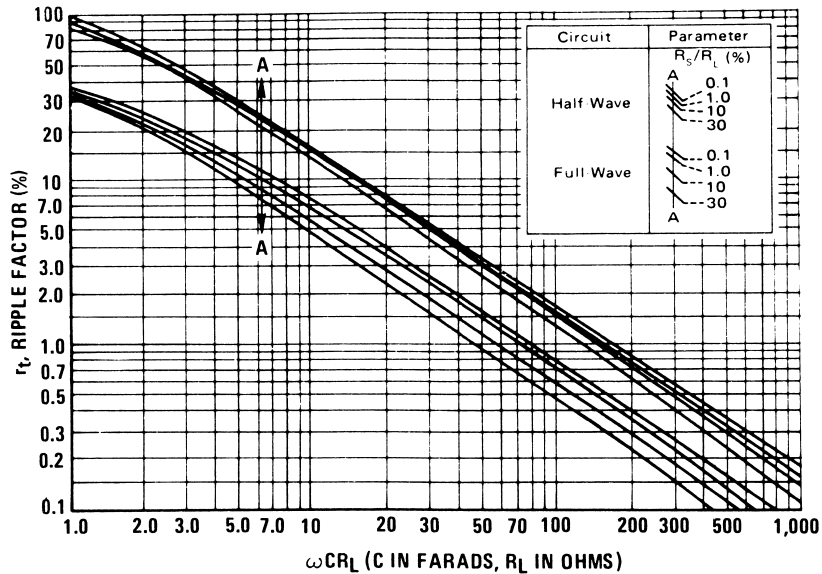


FIGURE 8.6. Root-Mean-Square Ripple Voltage for Capacitor-Input Circuits. (From O. H. Schade, Proc. IRE, vol. 31, p. 356, 1943.)

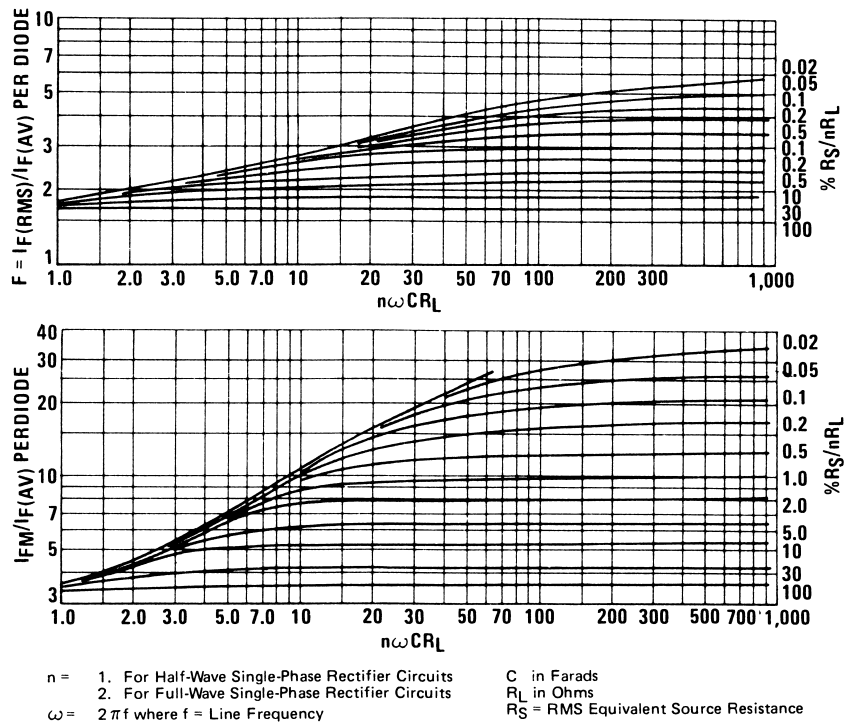


FIGURE 8.7. Relation of RMS and Peak to Average Diode Current in Capacitor-Input Circuits. (From O. H. Schade, Proc. IRE, vol. 31, p. 356, 1943.)

Transformer VA rating and secondary current ratings are determined as follows:

	FVB	FWCT	HW
$I_{RMS(SEC)}$	$= I_{IN(DC)} F / \sqrt{2}$	$I_{IN(DC)} F / 2$	$I_{IN(DC)} F$
VA_{SEC}	$= V_{RMS} I_{RMS}$	$2 V_{RMS} I_{RMS}$	$V_{RMS} I_{RMS}$
VA_{PRI}	$= VA_{SEC}$	$VA_{SEC} / \sqrt{2}$	VA_{SEC}

Where: $F = I_F(RMS) / I_{IN(DC)}$
 $=$ form factor from Figure 8.7

V_{RMS} = Secondary RMS voltage per leg

8.7 ADDITIONAL FILTER SECTIONS

Occasionally, it is desirable to add an additional filter to reduce ripple. When this is done, an LC filter section is cascaded with the single C section filter already designed. If the inductor is of low resistance, the effect on output voltage is small. The additional ripple reduction may be determined from Figure 8.9.

8.8 TRANSIENT PROTECTION

Often the PIV rating of the rectifier diodes must be considerably greater than the minimum value determined from Figure 8.8. This is due to the likely presence of high-voltage transients on the line. These transients may be as high as 400 V on a 115 V line. The transients are a result of switching inductive loads on the power line. Such loads could be motors, transformers, or could even be caused by SCR lamp dimmers or switching-type voltage regulators, or the reverse recovery transients in rectifying diodes. As the transients appearing on the transformer primary are coupled to the secondary, the rectifier diodes may see rather high peak voltages. A simple method of protecting against these transients is to use diodes with very high PIV. However, high-current diodes with very high PIV ratings can be expensive.

There are several alternate methods of protecting the rectifier diodes. All rely on the existence of some line impedance, primary transformer resistance or secondary circuit resistance. See Figure 8.10 for the system circuit.

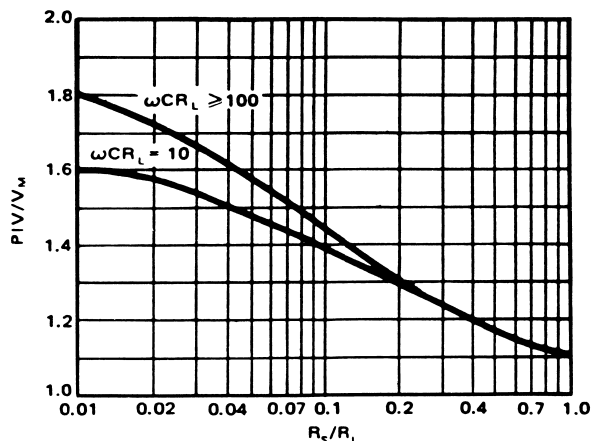


FIGURE 8.8. Ratio of Operating Peak Inverse Voltage to Peak Applied AC for Rectifiers Used in Capacitor-Input, Single-Phase, Filter Circuits

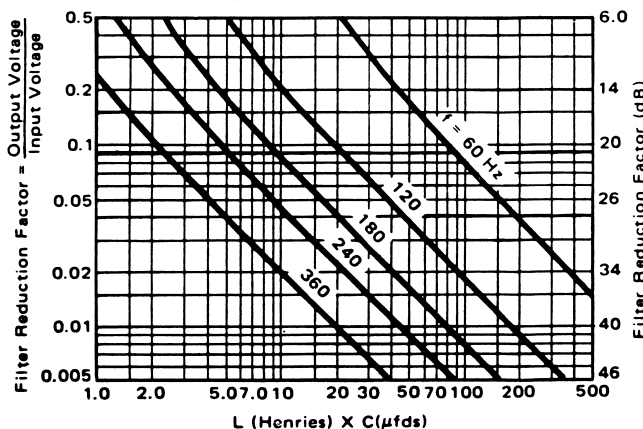


FIGURE 8.9. Reduction in Ripple Voltage Produced by a Single Section Inductance-Capacitance Filter at Various Ripple Frequencies

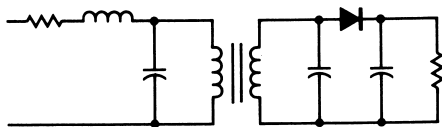


FIGURE 8.10. Transformer/Filter Circuit Showing Placement of Transient Protection Components

The several methods of transient protection rely on shunting the transient around the rectifier diodes to dissipate the transient energy in the series circuit resistance and the protective device. The usual protection methods are:

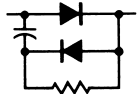
- Series resistor at the primary with shunt capacitor across the primary winding. See Figure 8.10.
- Series inductance at the primary, possibly with a shunt capacitor across the primary. See Figure 8.10.
- Shunt capacitor on the secondary. See Figure 8.10.
- Capacitor shunt on the rectifier diode. Transient power is thus dissipated in circuit series resistance.



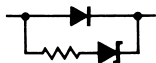
- Surge suppression varactor shunt on the rectifier diode. This scheme is quite effective, but costly.



- Dynamic clipper shunt on the rectifier diode. The clipper consists of an R, a C and a diode.



- Zener shunt on the rectifier diode; may also include a series resistance.

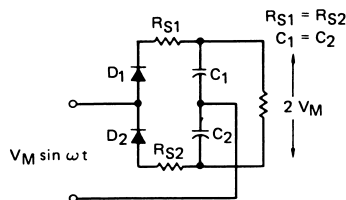


Of the several protective circuits

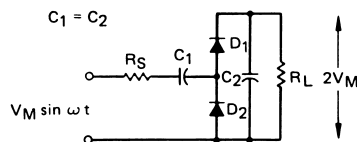
- a), b), c) and d) are least costly, but are limited in their utility to incomplete protection
- d) is probably the circuit providing the most protection for the money and is all that may be required in low-current regulated supplies
- e), f), and g) are most costly, but provide greatest protection. Their use is most worthwhile on high current supplies where high PIV ratings on high-current diodes is costly, or where very high transient voltages are encountered

8.9 VOLTAGE DOUBLERS

Occasionally, a voltage doubler is required to increase the voltage output from an existing transformer. Although the doubler circuits will provide increased output voltage, this is accomplished at the expense of an increased component count. Specifically, two filter capacitors are required. There are two basic types of doubler circuits as indicated in Figure 8.11. Figure 8.11 (a) is the conventional full-wave doubler circuit wherein two capacitors connected in series are charged on alternate half cycles of the line waveform. Figure 8.11 (b) is a half-wave doubler circuit wherein C_2 is partially charged on one half cycle and then on the second half cycle the input voltage is added to provide a doubling effect. C_1 is normally considerably larger than C_2 . The advantage of the half-wave circuit is that there is a common input and output terminal; disadvantages are high ripple, low I_O capability, and low V_{OUT} .



(a) Conventional Full-Wave Voltage Doubling Circuit



(b) Cascade (Half-Wave) Voltage Doubling Circuit

FIGURE 8.11. Voltage Doubler Circuits

These rectifying circuits, being capacitively loaded, exhibit high peak currents when energy is transferred to the capacitors. Filter design for the doubler circuits is similar to that of the conventional capacitor filter circuits. Figures 8.12, 8.13 and 8.14 provide the necessary design aids for full-wave voltage doubler circuits. They are used in the same way as Figures 8.5, 8.6 and 8.7.

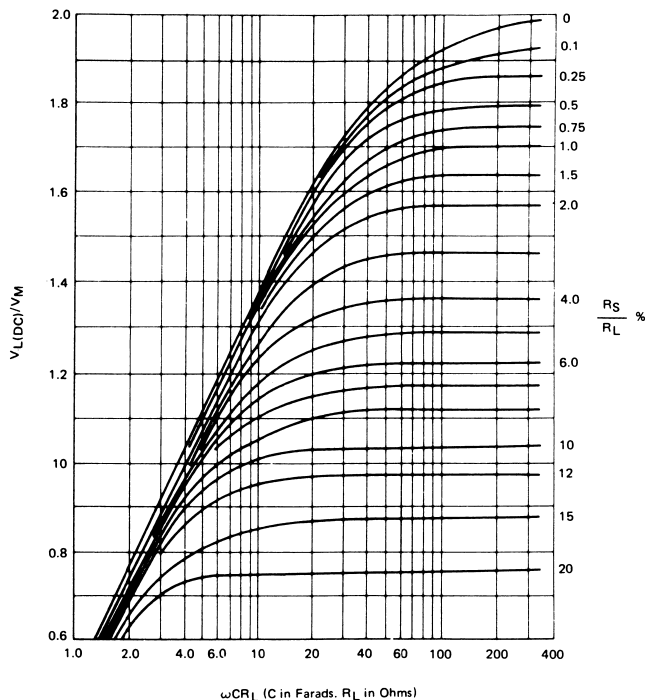


FIGURE 8.12. Output Voltage as a Function of Filter Constants for Full-Wave Voltage Doubler

8.10 DESIGN EXAMPLE

Design a 5 V, 3 A regulated supply using an LM123K. Determine the filter values and transformer and diode specifications. Ripple should be less than 7 mV rms. Assume 60 dB ripple reduction from typical curves.

- a) Establish operating conditions.

$$\omega = 377 \text{ rad/sec}$$

$V_{IN(PK)} = 18 \text{ V}$ at 10% high line voltage; this allows some 2 V headroom before reaching the 20 V absolute max V_{IN} rating of the LM123K

$V_{IN(MIN)} = 7.5 \text{ V}$ at 10% low line voltage including effects of ripple voltage

$V_{IN(DC)} = 11 \text{ V}$ at nominal line voltage; chosen to exceed $V_{IN(MIN)} + \text{peak ripple voltage}$

$$V_{\text{ripple(out)}} \leq 7 \text{ mV rms}$$

$$V_{\text{ripple(in)}} \leq 7 \text{ V rms}$$

$$r_{f(in)} \leq 7 \text{ V}/11 \text{ V} = 63.5\%$$

$$I_{IN} = 3 \text{ A}$$

$$I_{IN(MIN)} = I_Q = 20 \text{ mA}$$

$$R_L = 11 \text{ V}/3 \text{ A} = 3.67 \Omega$$

$$R_{L(MIN)} = 7.5 \text{ V}/3 \text{ A} = 2.5 \Omega$$

- b) Set

$V_M = 16.3 \text{ V}$ nominal, which is 18 V - 10% line variation

$$V_{IN(DC)}/V_M = 11/16.3 = 0.67$$

Assume full-wave bridge rectification because of the high current load. Enter the graph of Figure 8.5 at $V_{IN(DC)}/V_M = 0.67$ to intercept the "First Approximation" curve.

- c) Drop down to the horizontal axis to find $\omega CR_L = 3.33$.

Thus $R_S/R_L \approx 13\%$, or $R_S = 0.4 \Omega$ is allowable.

$$C = \frac{3.33}{3.67 \times 377} = 2400 \mu\text{F} \quad (4800 \mu\text{F} \text{ allowing for } \sim 50\% \text{ capacitor tolerance})$$

- d) Ripple factor is 15% from Figure 8.6. Ripple is then

$$V_{\text{ripple(pk)}} = \sqrt{2} \times 0.15 \times 11 = 1.88 \text{ V pk.}$$

- e) Checking for $V_{IN(MIN)}$

$V_M = 16.3 \text{ V}$; or, allowing for 10% low line voltage, 14.8 V.

$$V_{IN(DC)} = 14.8 \times 0.67 = 9.91 \text{ V.}$$

Subtracting peak ripple,

$V_{IN(MIN)} = 9.91 - 1.9 = 8.0 \text{ V}$, which is within specifications.

In fact, all requirements have been met.

f) Diode specifications are:

$$I_{F(AVG)} = \frac{I_{IN(DC)}}{2} = 1.5 \text{ A, for FW rectifiers}$$

$I_{FM} = 8 \times 1.5 \text{ A} = 12 \text{ A}$, from Figure 8.7, allowing
C = 100%, high for commercial tolerances.

$I_{SURGE} = 18 \text{ V} / 0.48 \Omega = 37.5 \text{ A}$ worst case with
10% high line, neglecting capacitor ESR

$I_{F(RMS)} = 2.1 \times 1.5 \text{ A} = 3.15 \text{ A}$ from Figure 9.7,
allowing for 100% high tolerance on C.

g) Transformer specifications are:

$$V_{SEC(RMS)} = \frac{16.3 + 1.4}{\sqrt{2}} = 12.6 \text{ for FWB,}$$

(24 VCT for FWCT)

$R_S = 0.48 \Omega$ including reflected primary resistance,
but subtract 2 x diode resistance

$$I_{AVG} = I_{IN(DC)} = 3 \text{ A}$$

$$I_{SEC(RMS)} = \frac{I_{IN(DC)} \times F}{\sqrt{2}} = \frac{3 \text{ A} \times 2.1}{1.414} = 4.45 \text{ A}$$

VA rating = $4.45 \text{ A} \times 12.6 = 56 \text{ VA}$, or 62 VA ,
allowing for 10% high line

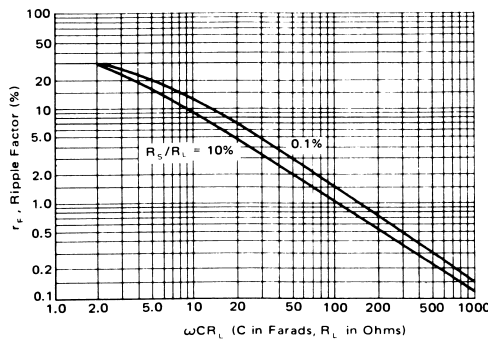
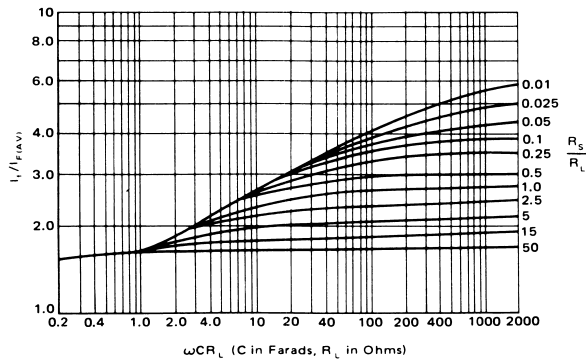


FIGURE 8.13. Ripple as a Function of Filter Constants for Full-Wave Voltage Doubler



RMS Rectifier Current as a Function of Filter Constants for Full-Wave Voltage Doubler

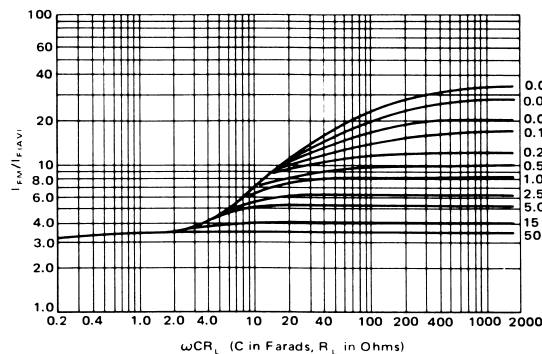
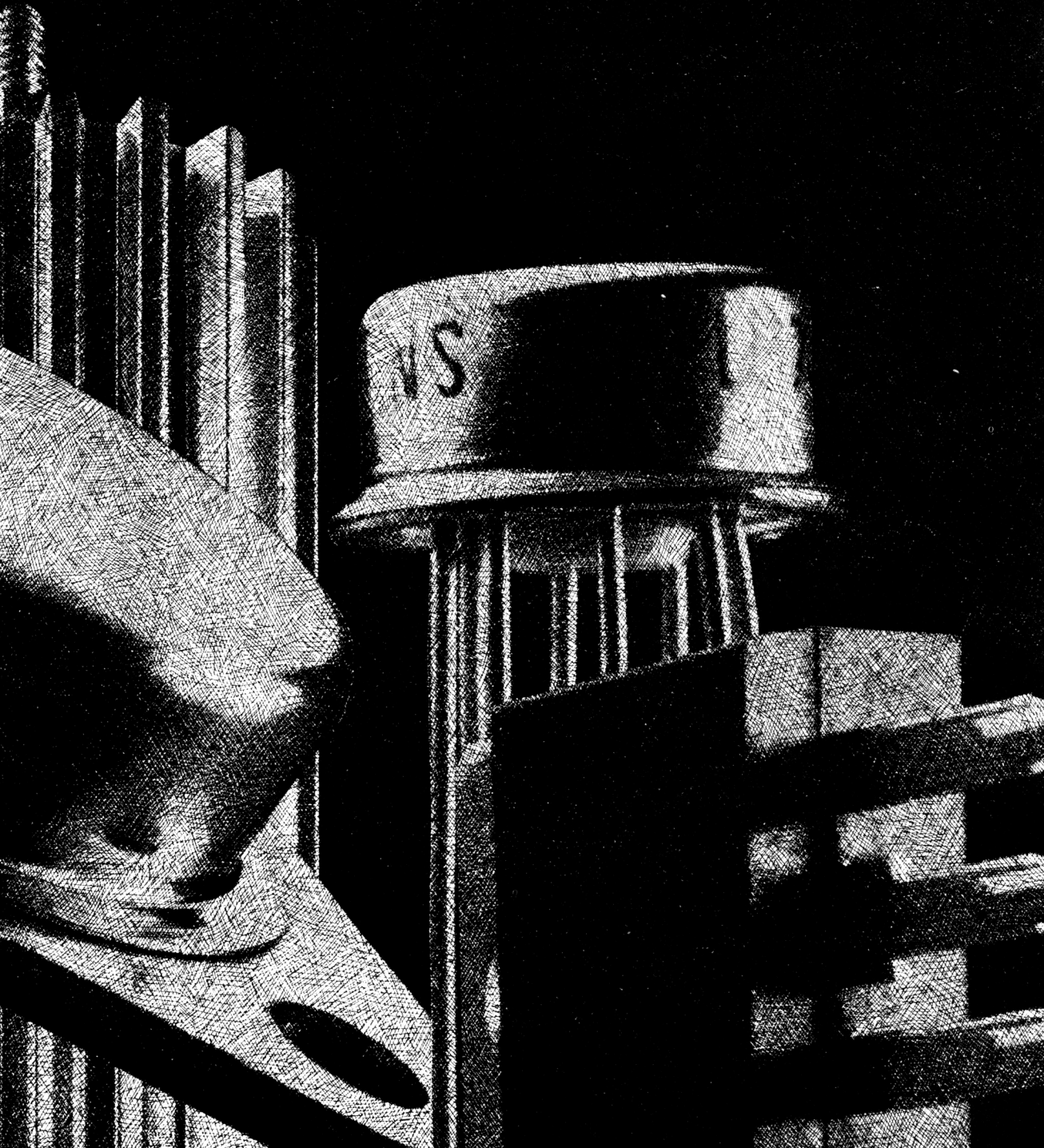


FIGURE 8.14. Relation of RMS to Peak and Average Diode Currents

Section 9.0 Appendix



A1 DEFINITION OF TERMS

L'_r , LINE REGULATION = The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

L_r , LOAD REGULATION = The change in output voltage for a change in load current at constant chip temperature. Also a pulse test.

DROPOUT VOLTAGE = The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. This is dependent upon load current and junction temperature.

I_Q , QUIESCENT CURRENT = That part of input current to the regulator which is not delivered to the load (+ or - standby current for the dual tracking regulators).

RIPPLE REJECTION = The ratio of rms input ripple voltage to rms output ripple voltage.

OUTPUT VOLTAGE BALANCE = The difference in magnitude of the positive and negative output voltage (dual tracking regulators only).

FORCED V_O = That voltage to which the output may be forced without damage to the device (dual tracking regulators).

OUTPUT NOISE VOLTAGE = The rms voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

LONG TERM STABILITY = Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

MAXIMUM POWER DISSIPATION = The maximum total device dissipation for which the regulator will operate within specifications.

θ_{JC} = Thermal resistance, junction to case.

θ_{JA} = Thermal resistance, junction to ambient.

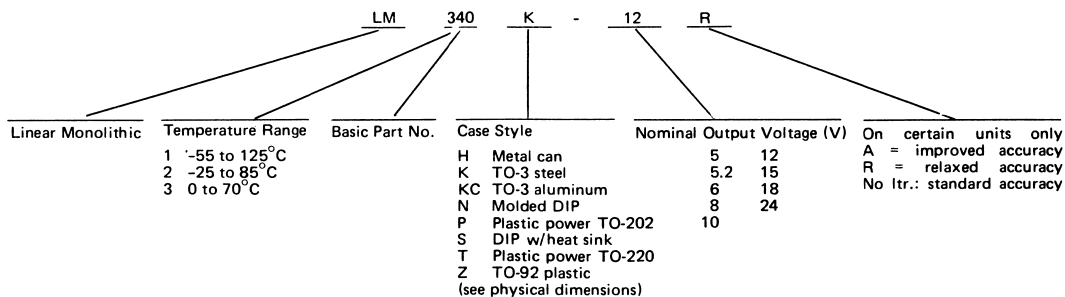
θ_{CA} = Thermal resistance, case to ambient.

θ_{CS} = Thermal resistance, case to heat sink.

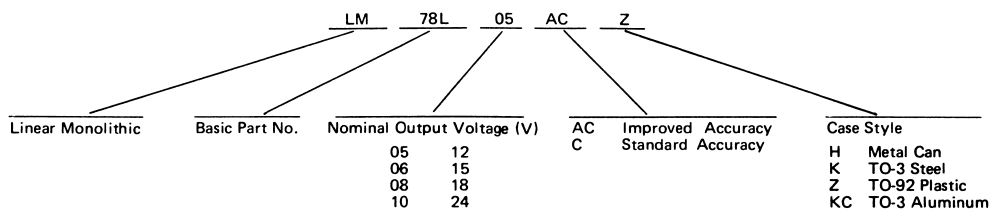
A2 ORDERING INFORMATION AND PHYSICAL DIMENSIONS

Voltage regulator part numbers include package type and voltage designations. Some also include the letter A or R to indicate respectively improved or relaxed specifications. Part number designation is as follows:

Not all regulator basic part numbers are available in all variations of temperature range, case style, or output voltage. See Figure 1.2, Table 2.1, or individual data sheets.

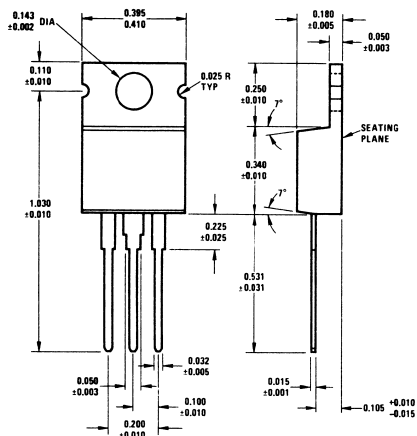


A few regulators use a somewhat different designation as follows:



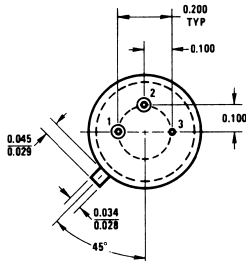
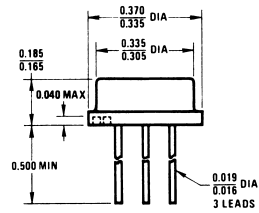
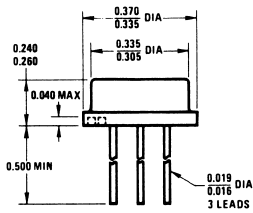
[illegible]

**Molded with Heat Sink
Dual-in-Line
(S) Package**

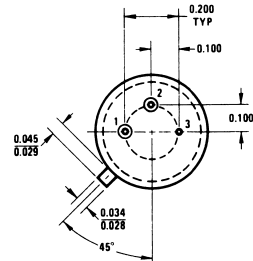
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9-3

PHYSICAL DIMENSIONS – PACKAGE OUTLINES (ALL DIMENSIONS IN INCHES)

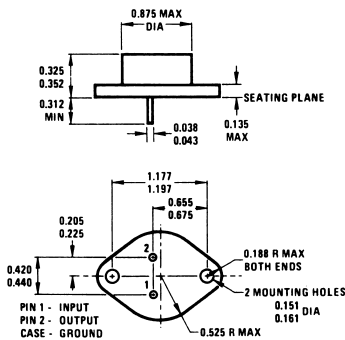


TO-39

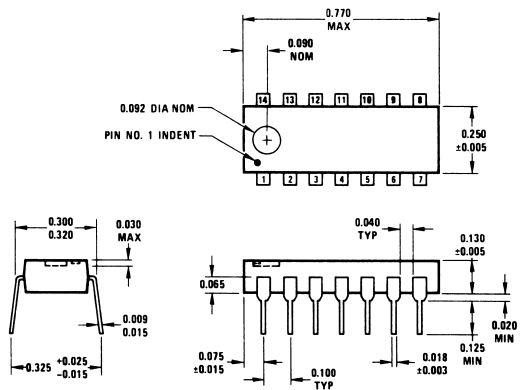


TO-39 with Tall Top

Metal Can (H) Package



**TO-3
Metal Can
(K) Steel Package
(KC) Aluminum Package**



**Molded Plastic
Dual-in-Line
(N) Package**

A3. INTERNAL CIRCUIT FEATURES

A3.1 Basic Regulator Operation

The basic circuit functions included in all of the three-terminal regulators are shown in Figure A3.1.

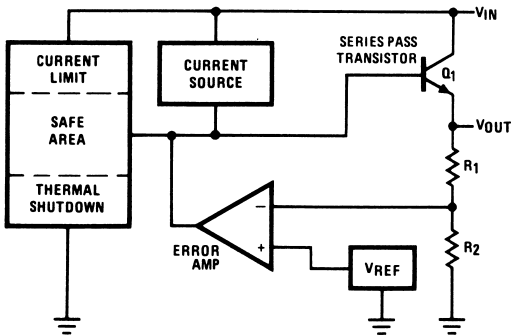


FIGURE A3.1. Basic Regulator

V_{REF} is a temperature-stabilized voltage developed from a zener or ΔV_{BE} circuit as discussed below. The error amplifier compares V_{REF} with a fraction of the output voltage determined by the feedback ratio of $R_2/(R_1 + R_2)$, and thereby controls the base drive of the series pass transistor to provide regulation.

All the regulator protection circuits, current limit, safe area and thermal shutdown, when activated, limit or turn off the base drive for the series pass transistor, so output current is either limited or the series pass transistor is turned completely off.

A3.2 The Voltage References

There are two types of references which are commonly used in the regulators. The first, known as a "band-gap" or ΔV_{BE} reference is shown in simplified form in Figure A3.2. Operation of this reference, which was first used in National's LM109, relies on the fact that two monolithic transistors operating at different current densities develop a predictable voltage, ΔV_{BE} , at the emitter of Q_2 :

$$\Delta V_{BE} = \frac{kT}{q} \ln \frac{I_1}{I_2}$$

This voltage, which has a positive temperature coefficient (TC), is amplified and added to the base-emitter voltage of Q_3 , which has a negative TC:

$$V_{REF} = \phi_3 + \frac{R_2}{R_1} \Delta V_{BE}$$

If the gain R_2/R_1 is properly chosen, the negative TC of ϕ_3 can be made to cancel the positive TC of ΔV_{BE} producing nearly zero temperature drift.

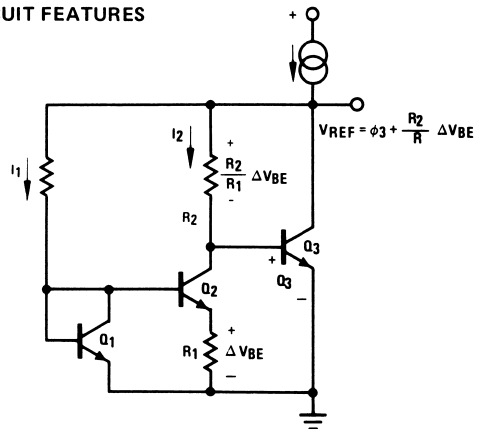


FIGURE A3.2. Simplified Schematic of Band Gap Reference

Advantages of the band-gap reference compared with a zener reference are: (1) low noise, since avalanche breakdown devices such as "zeners" are noisy, and (2) better long-term stability. This last property results since transistor V_{BE} 's are very stable and insensitive to surface effects. Disadvantages include: (1) it is more difficult to accurately control initial voltage tolerance since V_{BE} varies with transistor base width, (2) temperature drift is usually higher, and (3) thermal gradient effects (see below) are much more severe. The gradient effects arise because the band-gap reference consists of many components, each of which sees slightly different temperatures as heating occurs in the output transistor.

The major drawback of the zener reference, poor long-term stability, can be eliminated if the zener breakdown site is placed below the die surface where it is shielded from high field effects of mobile surface ions. It is difficult to achieve a controlled subsurface breakdown with normal diffusion techniques, but by using a new technology known as *ion implantation*, one can bury a highly doped region below the surface, thereby generating a stable and reproducible avalanche diode (see Figure A3.3). Such a diode is noisier than the band-gap reference, but most of this noise is eliminated by the normal output capacitor used on the regulator.

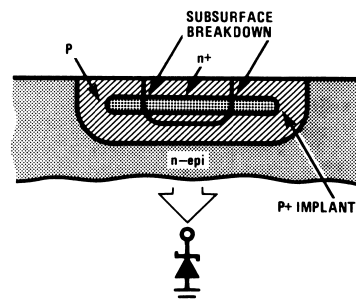


FIGURE A3.3. Zener (avalanche) Reference Employing Ion Implantation to Produce a Subsurface Breakdown

In National's line of three-terminal regulators, both band-gap and subsurface zeners are used. Band-gap references are generally chosen for the higher current devices (0.5 A to 3 A), where they offer low noise without significantly increasing die area, while zeners are chosen for small die, lower current (0.1 A and 0.25 A) devices. Because of the good initial voltage control with the zener, National offers $\pm 2\%$ initial voltage tolerances (LM3910 family) for users having a need for high precision.

A3.3 Operation of the Regulator in Fault Modes Current Limit

With $V_{IN} - V_{OUT}$ less than the 6 V breakdown of zener diode D_1 (Figure A3.4), there is no current in R_3 and only base current in R_4 . Therefore the base-emitter voltage on the current limit transistor Q_2 essentially equals the voltage developed across current limit sense resistor R_{CL} . As the regulator output current increases the voltage across R_{CL} and the base-emitter of Q_2 increases until Q_2 turns on, preventing additional base drive from reaching the series pass transistor Q_1 and thereby limiting the output current.

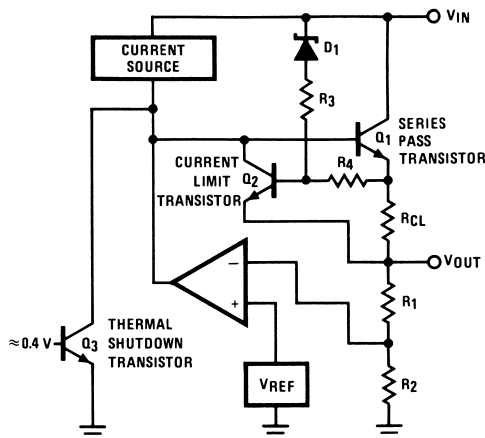


FIGURE A3.4. Basic Regulator with Protection Circuit

Safe Area Protection

With $V_{IN} - V_{OUT}$ greater than the breakdown voltage of D_1 , current proportional to $V_{IN} - V_{OUT}$ flows through D_1 , R_3 , and R_4 to the output. This causes the base-emitter voltage of Q_2 to be greater than the voltage drop across R_{CL} . Therefore Q_2 turns on at lower output currents through R_{CL} and the current limit point of the regulator is reduced. The rate of reduction of current limit with increase in $V_{IN} - V_{OUT}$ is equal to

$$\frac{\Delta I_{CL}}{\Delta(V_{IN} - V_O)} = - \frac{R_4}{R_3 R_{CL}}$$

amps per volt. This is the slope of the safe area curves in Figure A3.5. These curves also show a reduction in current limit with increased junction temperature, which results since a reduced base-emitter voltage is required to turn on the current limit transistor as its junction temperature increases. It is important to note in selecting a regulator that the safe area circuitry causes the maximum output current to drop significantly for large $V_{IN} - V_{OUT}$.

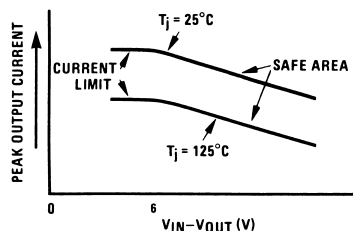


FIGURE A3.5. Peak Output Current Graph

Thermal Shutdown

The thermal shutdown transistor, Q_3 (Figure A3.4), is physically located next to Q_1 , the major heat source on the die. The base of Q_3 is held at approximately 0.4 V, which is below its turn-on voltage at room temperature. As the die temperature increases, the voltage required to turn on Q_3 will decrease to 0.4 V. When Q_3 turns on it removes all base drive from Q_1 and turns off the output. Various regulators have thermal shutdown temperatures ranging from 150°C to 190°C. The regulators also have hysteresis built into their thermal shutdown circuits so that the shutdown temperature is several degrees above the temperature at which the regulator turns back on. This reduces the chance of high frequency thermal oscillations.

A3.4 Output Impedance, Line and Load Regulation: Thermal and Electronic Effects

Few people realize that many of the important specification limits of high power regulators are determined by thermal characteristics rather than electrical ones. To illustrate, suppose a high current step load is placed on a regulator and the output voltage is observed on a storage oscilloscope as shown in Figure A3.6. The response is due to both electronic and thermal effects.

- Initially a large negative spike (not shown in Figure A3.6) can occur due to the presence of regulator and circuit lead inductance.
- This is followed by the electronic response of the regulator loop which will consist of a small negative step of a few microseconds duration. Details of this response are effected by the load

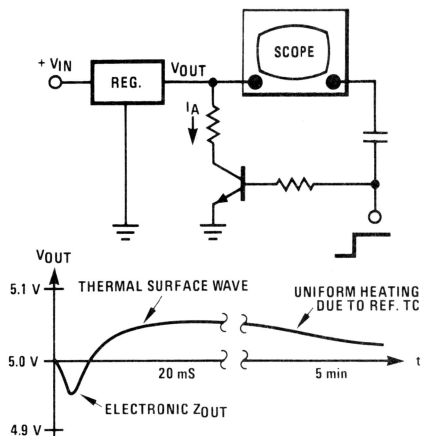


FIGURE A3.6. Thermal and Electronic Effects on Output Impedance for a Representative Regulator

capacitor used and by internal wirebond resistance in the regulator. Wirebond resistance ranges from approximately 150 milliohms in the 100 mA TO-92 regulators to 40 milliohms in the 1 A LM340. The 3 A regulators use electronic compensation to cancel effects of wire resistance, so this effect, which would otherwise dominate output impedance, can be ignored.

- c) As the electronic response decays, a third exponential response is observed with a time constant in the 20 mS to 40 mS region (see Figure A3.6). This is the major thermal response which results

from the "thermal surface wave." A qualitative feel for this thermal effect can be obtained by studying the simplified thermal model of the IC die and package shown in Figure A3.7. Referring to Figure A3.7 (b), we see that the power transistor and reference circuitry can be visualized as being coupled thermally by a distributed RC transmission line. This line is, of course, the electrical analog of a thermal line, with temperature replacing voltage, thermal resistances replacing normal Rs, etc.

Applying this electrical analog for a step increase of power in the pass transistor, it is seen that there is an immediate increase in the power transistor temperature, T_p . Temperature gradients then begin to set up across the die as the heat propagates through the die (transmission line), see Figure A3.7 (a). The various components of the reference circuitry now are no longer at a single temperature, so small thermally-induced shifts occur in the reference voltage. These shifts then reflect to the output as a change in output voltage in response to a change in *dissipated power* in the pass transistor. We see, therefore, that changes in either load current or input voltage can cause a thermal response, so both load and line regulation have thermal components.

- d) The last portion of the response in Figure A3.6 shows a long term (minutes) settling effect, which is due largely to uniform heating effects in the die, header and sink. Such heating gives rise to normal temperature drift effects in the voltage reference which then reflect as small output voltage changes.

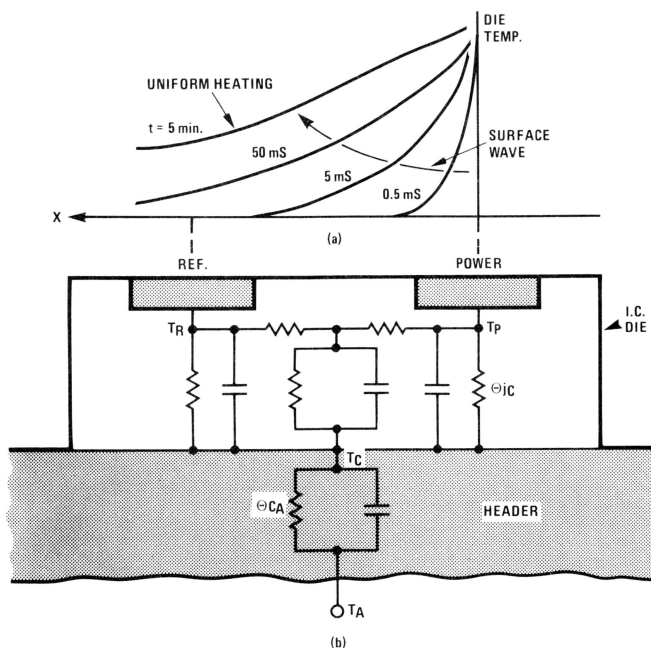


FIGURE A3.7(a). Plot of Die Temperature vs. Distance (x) Along Die After Power Transistor is Turned On.
(b). Simplified thermal model of IC power regulator mounted to metal header.

A4 TEST CIRCUITS

Figure A4.1 illustrates a circuit for testing line and load regulation, I_Q variations and output voltage of a positive three-terminal regulator. For line and load regulation, a pulse technique is used. An LM555CN timer, connected as an astable multivibrator, is the pulse generator. Duty cycle and pulse width can be adjusted with R_A and R_B . The test method is summarized in Table A4.1.

Notice that line regulation is measured with constant load and pulsed input voltage, whereas load regulation is measured with constant input voltage and pulsed load.

Figure A4.2 shows a similar test circuit for negative three-terminal regulators. The schematic does not include a pulse generator, but an LM555CN can be used for generating variable amplitude negative pulses to drive the PNP switch Q_3 . The loop composed of the two LM101As insures that line voltage variation is within data sheet specifications for LM120, independent of the value of the fixed output voltages of the negative regulator. An LM101A converted as a current-to-voltage converter, is used to monitor quiescent current variations during the load and line regulation test.

The test method is summarized in Table A4.2.

During any kind of measurement the regulator should be lightly preloaded as already shown [$R_P = 0.2 V_{OUT} (k\Omega)$].

Load and line regulation of a dual tracking regulator can be tested in the circuit of Figure A4.3.

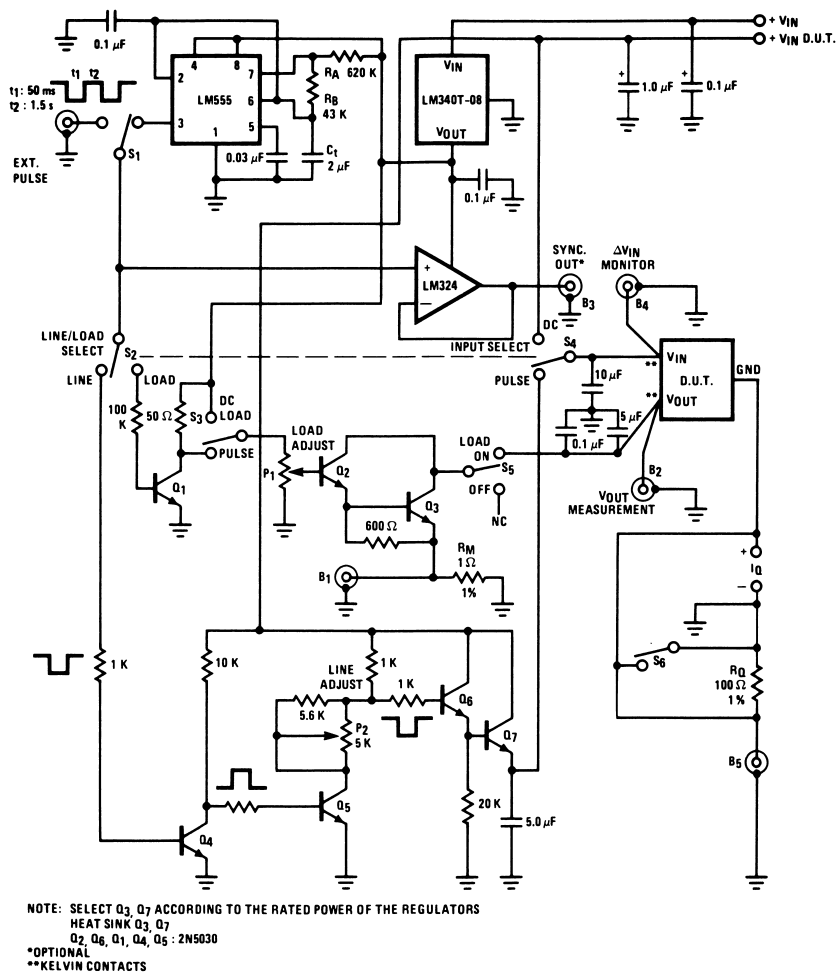


FIGURE A4.1. Test Circuit for Three Terminal Positive Regulators

TABLE A4.1.

TEST	SWITCH POSITIONS					Measurement at Connector
	S ₂	S ₃	S ₄	S ₅	S ₆	
Load Regulation (pulsed mode)	LOAD	PULSE	DC	ON	CLOSED	B ₂
Line Regulation (DC load ON)	LINE	DC	PULSE	ON	CLOSED	B ₂
Quiescent current, I _Q	LOAD	DC	DC	ON	OPEN	B ₅
I _Q change: 1) with load	LOAD	PULSE	DC	ON	OPEN	B ₅
2) with line	LINE	DC	PULSE	ON	OPEN	B ₅
Output Voltage	LOAD	DC	DC	ON	CLOSED	B ₂

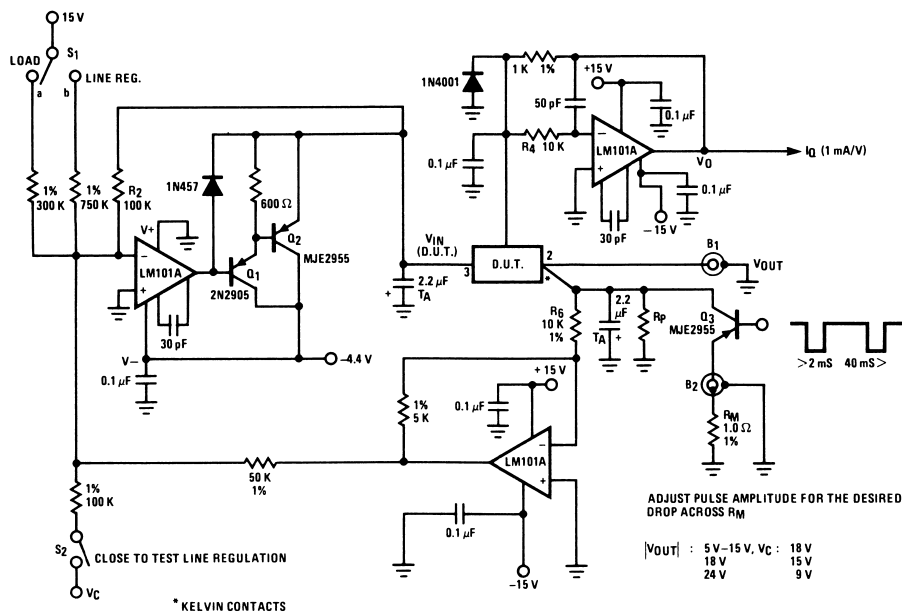


FIGURE A4.2. LM320 Test Circuit

TABLE A4.2.

TEST	Q ₃	S ₁	S ₂	Measurement at Connector
Load Regulation	ON-OFF	a	open	B ₁
Line Regulation	OFF	b	open-close	B ₁
Quiescent current, I _Q	OFF	a	open	V _O
I _Q change: 1) with load	ON-OFF	a	open	V _O
2) with line	OFF	b	open-closed	V _O

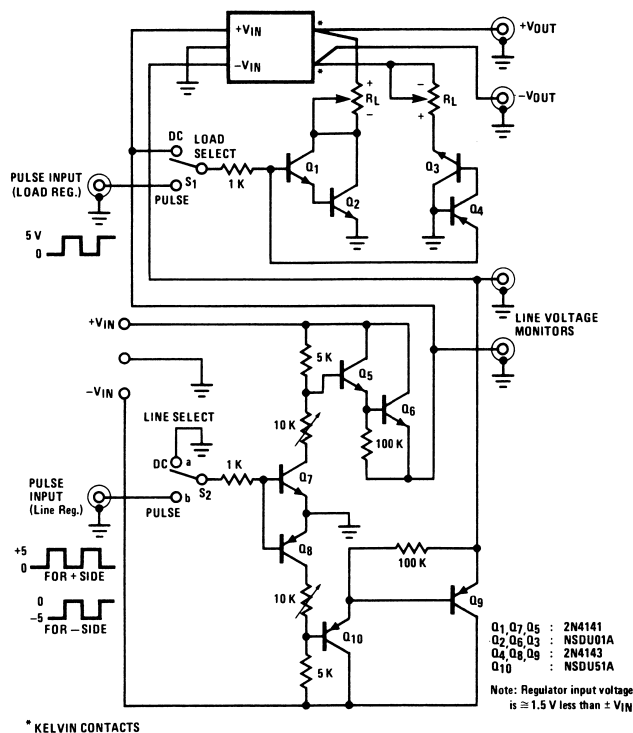


Figure A4.3. Line and Load Regulation Test Circuit for the Dual Tracking Regulators

TABLE A4.3.

TEST	S ₁	S ₂	Measure
Line regulation	DC	PULSE	$\pm V_{OUT}$
Load regulation	PULSE	DC	$\pm V_{OUT}$

A5 RELIABILITY

For steady state operation within the operating junction temperature range of the part, most failure modes are due to die surface related effects such as zener voltage drift due to field effect changes caused by movement of ions in the oxide. After extensive life testing, National Semiconductor has developed some average "acceleration factors" relating increased surface related failure rates to increased junction temperature. For example: an IC device operating steady state at $T_J = 125^\circ\text{C}$ for 500 hours will experience approximately the same failure rate as if operated at $T_J = 70^\circ\text{C}$ for 72,500 hours. The acceleration factor from 70°C to 125°C (T_J) would be 145. From 125°C to 150°C (T_J) the acceleration factor is 6.3. This indicates the greatly increased part lifetime the user can realize by maintaining the part at a low operating junction temperature.

A6 VOLTAGE REGULATOR CROSS REFERENCE GUIDE

RAYTHEON

Part #	Package	Voltage	Temp.	Max. Current	NSC Equiv.
RC4194TK	TO-66	Variable	COM	250mA	-
RM4194TK	TO-66	Variable	MIL	250mA	-
RC4194D	TO-116 DIP	Variable	COM	150mA	-
RM4194D	TO-116 DIP	Variable	MIL	150mA	-
RC4195TK	TO-66	115	COM	150mA	*LM325S
RM4195TK	TO-66	115	MIL	150	*LM125S
RC4195T	TO-99	115	COM	150	*LM325H
RM4195T	TO-99	115	MIL	150	*LM125H
RC4195DN	TO-116 DIP	115	COM	150	*LM325N

* Not pin for pin equivalent.

LM104H	TO-78	Variable	MIL	20 mA	LM104H
LM204H	TO-78	Variable	IND	20 mA	LM204H
LM304H	TO-78	Variable	COM	20 mA	LM304H
LM104F	TO-86	Variable	MIL	20 mA	LM104F
LM105H	TO-78	Variable	MIL	25 mA	LM105H
LM205H	TO-78	Variable	IND	25 mA	LM205H
LM305H	TO-78	Variable	COM	25 mA	LM305H
LM105AH	TO-78	Variable	MIL	25 mA	-
LM205AH	TO-78	Variable	IND	25 mA	-
LM305AH	TO-78	Variable	COM	25 mA	LM305AH
LM105F	TO-86	Variable	MIL	25 mA	LM105F
LM105AF	TO-86	Variable	MIL	25 mA	-
LM109K	TO-3	5 V	MIL	1.5 A	LM109K
LM209K	TO-3	5 V	IND	1.5 A	LM209K
LM309K	TO-3	5 V	COM	1.5 A	LM309K
LM109H	TO-78	5 V	MIL	.5 A	LM109H
LM209H	TO-78	5 V	IND	.5 A	LM209H
LM309H	TO-78	5 V	COM	.5 A	LM309H
RM723T	TO-78	Variable	MIL	150 mA	LM723H
RC723T	TO-78	Variable	COM	150 mA	LM723CH
RM723D	TO-116	Variable	MIL	150 mA	LM723D
RC723D	TO-116	Variable	COM	150 mA	LM723CD
RC723DP	TO-116	Variable	COM	150 mA	LM723CN

MOTOROLA

MC7805CP		5 V	COM	1.5 A	LM340T-5.0
MC7806CP		6 V	COM	1.5 A	LM340T-6.0
MC7808CP		8 V	COM	1.5 A	LM340T-8.0
MC7812CP		12 V	COM	1.5 A	LM340T-12
MC7815CP		15 V	COM	1.5 A	LM340T-15
MC7818CP		18 V	COM	1.5 A	LM340T-18
MC7824CP		24 V	COM	1.5 A	LM340T-24
MC7805CK	TO-3	5 V	COM	1.5 A	LM340K-5.0
MC7806CK	TO-3	6 V	COM	1.5 A	LM340K-6.0
MC7808CK	TO-3	8 V	COM	1.5 A	LM340K-8.0
MC7812CK	TO-3	12 V	COM	1.5 A	LM340K-12
MC7815CK	TO-3	15 V	COM	1.5 A	LM340K-15
MC7818CK	TO-3	18 V	COM	1.5 A	LM340K-18
MC7824CK	TO-3	24 V	COM	1.5 A	LM340K-24

MOTOROLA (Cont'd)

Part #	Package	Voltage	Temp.	Max. Current	NSC Equiv.
MC7902CP		-2 V	COM	1 A	-
MC7905CP		-5 V	COM	1 A	LM320T-5.0
MC7905.2CP		-5.2 V	COM	1 A	LM320T-5.2
MC7906CP		-6 V	COM	1 A	LM320T-6.0
MC7908CP		-8 V	COM	1 A	-
MC7912CP		-12 V	COM	1 A	LM320T-12
MC7915CP		-15 V	COM	1 A	LM320T-15
MC7918CP		-18 V	COM	1 A	LM320T-18
MC7924CP		-24 V	COM	1 A	LM320T-24
MC7902CK	TO-3	-2 V	COM	1 A	-
MC7905CK	TO-3	-5 V	COM	1 A	LM320K-05
MC7905.2CK	TO-3	-5.2 V	COM	1 A	LM320K-5.2
MC7906CK	TO-3	-6 V	COM	1 A	LM320K-06
MC7908CK	TO-3	-8 V	COM	1 A	LM320K-08
MC7912CK	TO-3	-12 V	COM	1 A	LM320K-12
MC7915CK	TO-3	-15 V	COM	1 A	LM320K-15
MC7918CK	TO-3	-18 V	COM	1 A	LM320K-18
MC7924CK	TO-3	-24 V	COM	1 A	LM320K-24
MC1723L	Cer. DIP	Variable	MIL	150 mA	LM723D
MC1723G	TO-78	Variable	MIL	150 mA	LM723H
MC1723CL	Cer. DIP	Variable	COM	150 mA	LM723CD
MC1723CG	TO-78	Variable	COM	150 mA	LM723CH
MLM105G	TO-78	Variable	MIL	20 mA	LM105 H
MLM109K	TO-3	5 V	MIL	1.5 A	LM109K
MLM205G	TO-78	Variable	MIL	20 mA	LM205H
MLM305G	TO-78	Variable	COM	20 mA	LM305H
MLM309K	TO-3	5 V	COM	1.5 A	LM309K
MC1468R	TO-3	115 V	COM	100 mA	*LM325S
MC1468G	TO-78	115 V	COM	100 mA	*LM325H
MC1468L	DIP	115 V	COM	100 mA	*LM325N
MC1568R	TO-3	115 V	MIL	100 mA	*LM325S
MC1568G	TO-78	115 V	MIL	100 mA	*LM325H

* Not pin for pin equivalent.

TI

SN72905	TO-220	5 V	COM	1.5 A	LM340T-05
SN72906	TO-220	6 V	COM	1.5 A	LM340T-06
SN72908	TO-220	8 V	COM	1.5 A	LM340T-08
SN72912	TO-220	12 V	COM	1.5 A	LM340T-12
SN72915	TO-220	15 V	COM	1.5 A	LM340T-15
SN72918	TO-220	18 V	COM	1.5 A	LM340T-18
SN72924	TO-220	24 V	COM	1.5 A	LM340T-24
SN72304	TO-5/DIP	Variable	COM	20 mA	LM304H/N
SN72305	TO-5/DIP	Variable	COM	25 mA	LM305H/N
SN72305A	TO-5/DIP	Variable	COM	25 mA	LM305H/N
SN72309	TO-5/DIP	5 V	COM	.5 A	LM309H/K
SN72723	TO-5/DIP	Variable	MIL	150 mA	LM723CH/N
SN72376	DIP	Variable	COM	25 mA	LM376N
SN52104	TO-5	Variable	MIL	20 mA	LM104H
SN52105	TO-5	Variable	MIL	25 mA	LM105 H
SN52109	TO-5	5 V	MIL	.5 A	LM109K/H
SN52723	TO-5	Variable	MIL	150 mA	LM723H

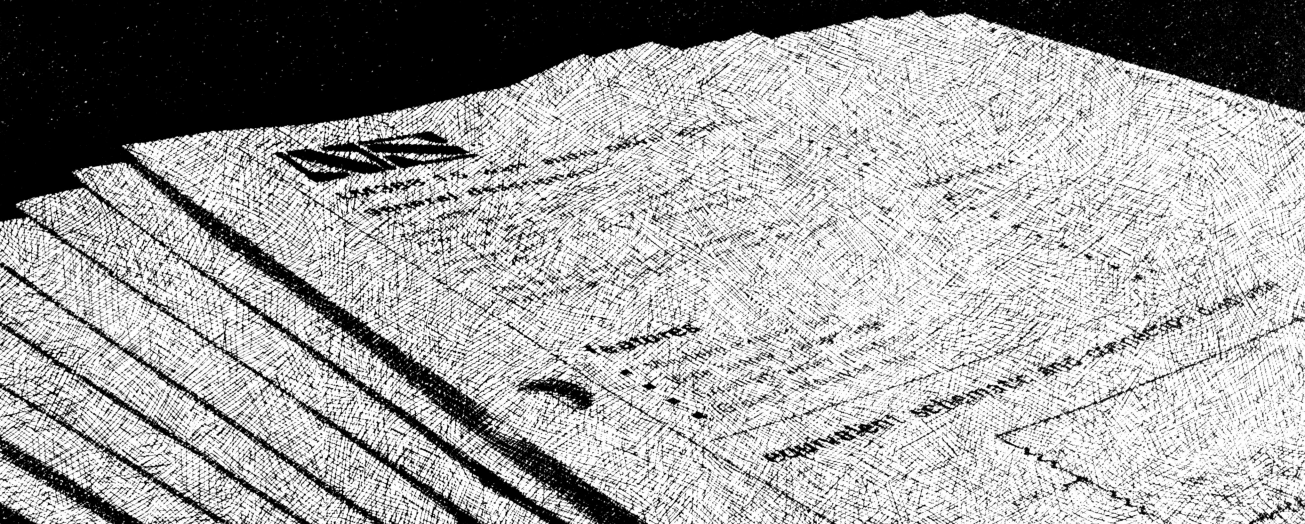
FAIRCHILD

7805KM	TO-3	5 V	MIL	1.5 A	LM140K-05
7806KM	TO-3	6 V	MIL	1.5 A	LM140K-06
7808KM	TO-3	8 V	MIL	1.5 A	LM140K-08
7812KM	TO-3	12 V	MIL	1.5 A	LM140K-12
7815KM	TO-3	15 V	MIL	1.5 A	LM140K-15
7818KM	TO-3	18 V	MIL	1.5 A	LM140K-18
7824KM	TO-3	24 V	MIL	1.5 A	LM140K-24

FAIRCHILD (Cont'd)

Part #	Package	Voltage	Temp.	Max. Current	NSC Equiv.
7805KC	TO-3 Aluminum	5 V	COM	1.5 A	LM7805KC
7806KC	TO-3 Aluminum	6 V	COM	1.5 A	LM7806KC
7808KC	TO-3 Aluminum	8 V	COM	1.5 A	LM7808KC
7812KC	TO-3 Aluminum	12 V	COM	1.5 A	LM7812KC
7815KC	TO-3 Aluminum	15 V	COM	1.5 A	LM7815KC
7818KC	TO-3 Aluminum	18 V	COM	1.5 A	LM7818KC
7824KC	TO-3 Aluminum	24 V	COM	1.5 A	LM7824KC
7805UC	TO-220	5 V	COM	1.5 A	LM340T-05
7806UC	TO-220	6 V	COM	1.5 A	LM340T-06
7808UC	TO-220	8 V	COM	1.5 A	LM340T-08
7812UC	TO-220	12 V	COM	1.5 A	LM340T-12
7815UC	TO-220	15 V	COM	1.5 A	LM340T-15
7819UC	TO-220	18 V	COM	1.5 A	LM340T-18
7824UC	TO-220	24 V	COM	1.5 A	LM340T-24
78M05HM	TO-39	5 V	MIL	500 mA	LM341H-05
78M06HM	TO-39	6 V	MIL	500 mA	LM341H-06
78M08HM	TO-39	8 V	MIL	500 mA	LM341H-08
78M12HM	TO-39	12 V	MIL	500 mA	LM341H-12
78M15HM	TO-39	15 V	MIL	500 mA	LM341H-15
78M18HM	TO-39	20 V	MIL	500 mA	LM341H-18
78M24HM	TO-39	24 V	MIL	500 mA	LM341H-24
78M05HC	TO-39	5 V	COM	500 mA	LM341H-05
78M06HC	TO-39	6 V	COM	500 mA	LM341H-06
78M08HC	TO-39	8 V	COM	500 mA	LM341H-08
78M12HC	TO-39	12 V	COM	500 mA	LM341H-12
78M15HC	TO-39	15 V	COM	500 mA	LM341H-15
78M18HC	TO-39	18 V	COM	500 mA	LM341H-18
78M24HC	TO-39	24 V	COM	500 mA	LM341H-24
78M05UC	TO-220	5 V	COM	500 mA	LM341P-05
78M06UC	TO-220	6 V	COM	500 mA	LM341P-06
78M08UC	TO-220	8 V	COM	500 mA	LM341P-08
78M12UC	TO-220	12 V	COM	500 mA	LM341P-12
78M15UC	TO-220	15 V	COM	500 mA	LM341P-15
78M18UC	TO-220	18 V	COM	500 mA	LM341P-18
78M24UC	TO-220	24 V	COM	500 mA	LM341P-24
78L05HC	TO-39	5 V	COM	100 mA	LM78L05CH
78L05WC	TO-92	5 V	COM	100 mA	LM78L05CZ
78L05AHC	TO-39	5 V	COM	100 mA	LM78L05ACH
78L05AWC	TO-92	5 V	COM	100 mA	LM78L05ACZ
78L05WC	TO-39	6 V	COM	100 mA	LM78L06CZ
78L06AWC	TO-92	6 V	COM	100 mA	LM78L06ACZ
78L12HC	TO-39	12 V	COM	100 mA	LM78L12CH
78L12WC	TO-92	12 V	COM	100 mA	LM78L12CZ
78L12AHC	TO-39	12 V	COM	100 mA	LM78L12ACH
78L12AWC	TO-92	12 V	COM	100 mA	LM78L12ACZ
78L15HC	TO-39	15 V	COM	100 mA	LM78L15CH
78L15WC	TO-92	15 V	COM	100 mA	LM78L15CZ
78L15AHC	TO-39	15 V	COM	100 mA	LM78L15ACH
78L15AWC	TO-92	15 V	COM	100 mA	LM78L15ACZ

Section 10.0 Data Sheets





Voltage Regulators

LM109/LM209/LM309 five-volt regulators

general description

These voltage regulators are complete 5V regulators fabricated on a single silicon chip. They are designed for local regulation on digital logic cards, eliminating the distribution problems associated with single-point regulation. The devices are available in two common transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1A.

The regulators are essentially blow-out proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating.

Considerable effort was expended to make these devices easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient

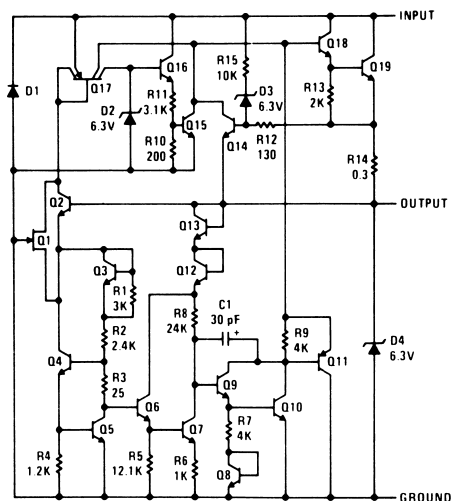
response somewhat. Input bypassing is needed, however, if the regulator is located very far from the filter capacitor of the power supply. Stability is also achieved by methods that provide very good rejection of load or line transients as are usually seen with TTL logic.

Although designed primarily as a fixed-voltage regulator, the output voltage can be set to voltages above 5V, as shown in Section 7.1.5. It is also possible to use the circuits as the control element in precision regulators, taking advantage of the good current-handling capability and the thermal overload protection.

To summarize, outstanding features of the regulator are:

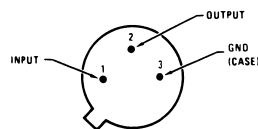
- Specified to be complete, worst case, with TTL and DTL
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required

schematic diagram



connection diagrams

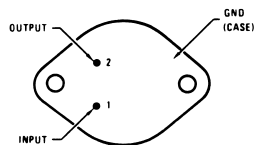
TO-39 (H)



BOTTOM VIEW

Order Numbers
LM109H
LM209H
LM309H

TO-3 (K)



BOTTOM VIEW

Order Numbers
LM109K
LM209K
LM309K

electrical characteristics

(Note 1) (unless noted)

$T_J = -55^{\circ}\text{C}$ to $+150^{\circ}\text{C}$ LM109
 -25°C to $+150^{\circ}\text{C}$ LM209
 $+50^{\circ}\text{C}$ to $+125^{\circ}\text{C}$ LM309
 $I_O = 100\text{ mA}$ for H package devices
 500 mA for K package devices

absolute maximum ratings

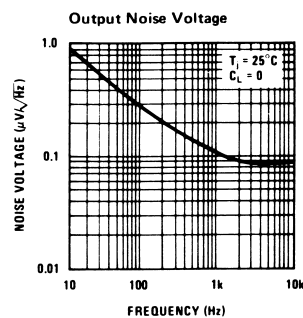
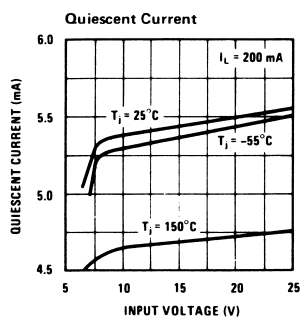
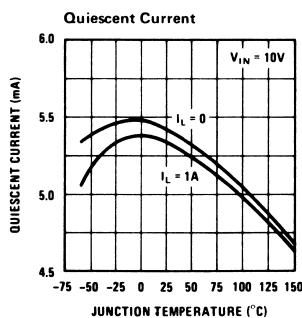
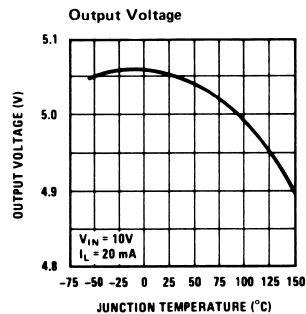
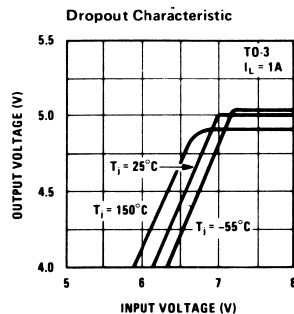
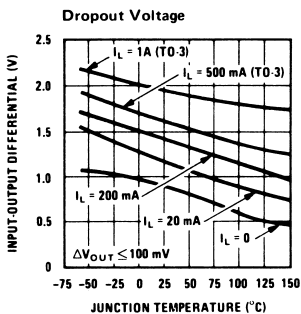
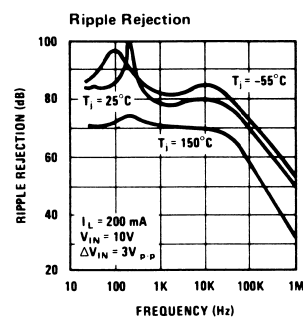
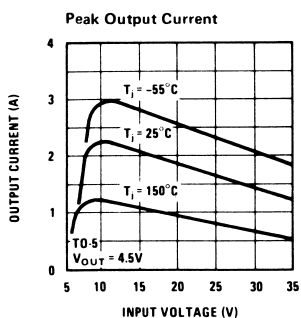
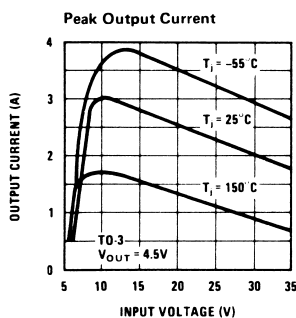
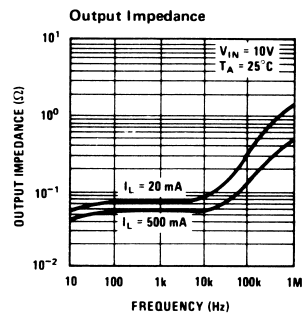
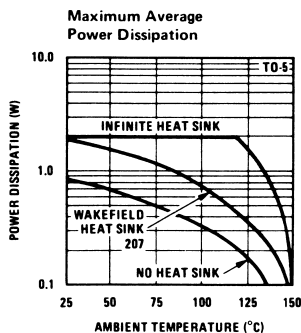
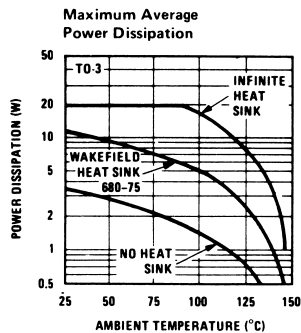
Input Voltage 35 V
 Power Dissipation Internally Limited
 Operating Junction Temperature Range -55°C to $+150^{\circ}\text{C}$
 Storage Temperature Range -65°C to $+150^{\circ}\text{C}$
 Lead Temperature (Soldering, 10 seconds) $+300^{\circ}\text{C}$

Part Number		LM109			LM209			LM309			Units
Input Voltage (unless otherwise noted)		10 V			10 V			10 V			
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V _O	T _J = 25°C	4.7	5.05	5.3	4.7	5.05	5.3	4.8	5.05	5.2	V
	P _D ≤ P _D (MAX) I _O = 5 mA - I _{MAX}	4.6		5.4	4.6		5.4	4.75		5.25	
	V _{IN} = 7 - 25 V										
ΔV _O	Line Regulation		4	50		4	50		4	50	mV
	Load Regulation		20	50		20	50		20	50	
			50	100		50	100		50	100	
	Long Term Stability			10			10			20	$\frac{\text{mV}}{1000 \text{ hrs}}$
I _Q	Quiescent Current		5.2	10		5.2	10		5.2	10	mA
ΔI _Q	Quiescent Current Change			0.5			0.5			0.5	
				0.8			0.8			0.8	
v _n	Output Noise Voltage		40			40			40		μV
	f = 10 Hz - 100 kHz										
θ _{JC}	Thermal Resistance, Junction-to-Case										°C/W
			15			15			15		
			3			3			3		

Note 1: For the TO-5 package, $I_{\text{MAX}} = 0.2\text{ A}$ and $P_{\text{MAX}} = 2.0\text{ W}$. For the TO-3 package, $I_{\text{MAX}} = 1.0\text{ A}$ and $P_{\text{MAX}} = 20\text{ W}$.

Note 2: Without a heat sink, the thermal resistance of the TO-5 package is about 150°C/W , while that of the TO-3 package is approximately 35°C/W . With a heat sink, the effective thermal resistance can only approach the values specified, depending on the efficiency of the sink.

typical performance characteristics





Voltage Regulators

LM120/LM220/LM320 series three-terminal negative regulators

general description

The LM120 Series are three-terminal negative regulators with a fixed output voltage of -5V, -5.2V, -6V, -8V, -12V, -15V, -18V and -24V and up to 1.5A load current capability. These devices need only one external component — a compensation capacitor at the output, making them easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM120 Series immune to overload conditions. The regulators have current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shutdown prevents junction temperatures from exceeding safe limits during prolonged overloads.

Although primarily intended for fixed output voltage applications, the LM120 Series may be pro-

grammed for higher output voltages with a simple resistive divider. The low quiescent drain current of the devices allows this technique to be used with good regulation.

The LM120 Series is available in TO-5 and TO-3 packages. The TO-5 is rated at 200 mA and 2W; the TO-3 at 1A and 20W.

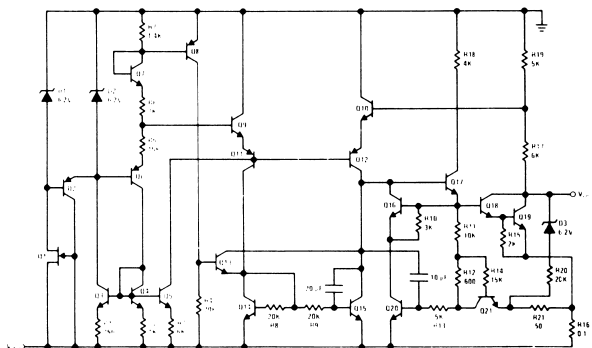
The LM320T Series is packaged in the easy to use Epoxy B TO-220 rated at 15 watts dissipation.

features

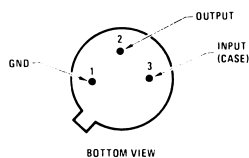
- Preset output voltage error less than $\pm 3\%$
- Preset current limit
- Internal thermal shutdown
- Operates with input-output voltage differential down to 1V
- Excellent ripple rejection
- 50 mV load regulation

schematic and connection diagrams

TYPICAL



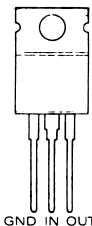
TO-5(H)



Order Numbers:

LM120H-5.0 LM120H-5.2 LM120H-6.0 LM120H-12
LM220H-5.0 LM220H-5.2 LM220H-6.0 LM220H-12
LM320H-5.0 LM320H-5.2 LM320H-6.0 LM320H-12
LM120H-15 LM120H-18 LM120H-24
LM220H-15 LM220H-18 LM220H-24
LM320H-15 LM320H-18 LM320H-24

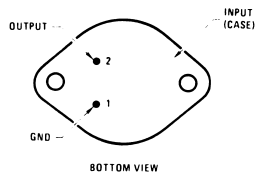
TO-220 (T)



Order Numbers

LM320T-5.0 LM320T-12
LM320T-5.2 LM320T-15
LM320T-6.0 LM320T-18
LM320T-8.0 LM320T-24

TO-3 (K)



Order Numbers:

LM120K-5.0 LM120K-5.2 LM120K-6.0 LM120K-12
LM220K-5.0 LM220K-5.2 LM220K-6.0 LM220K-12
LM320K-5.0 LM320K-5.2 LM320K-6.0 LM320K-12
LM120K-15 LM120K-18 LM120K-24
LM220K-15 LM220K-18 LM220K-24
LM320K-15 LM320K-18 LM320K-24

electrical characteristics

(Note 1) unless noted

$T_J = -55^{\circ}\text{C}$ to $+150^{\circ}\text{C}$ LM120 series
 -25°C to $+150^{\circ}\text{C}$ LM220 series
 0°C to $+150^{\circ}\text{C}$ LM320 series
 $I_O = 100\text{ mA}$ for H package devices
 $= 500\text{ mA}$ for K package devices

absolute maximum ratings

Input Voltage
 (LM120 Series)

-25 V

Input Voltage

($V_O = 5.0\text{ V} - 5.2\text{ V}$)
 ($V_O = 12\text{ V}$)
 ($V_O = 15\text{ V}$)

-25 V
 -35 V
 -40 V

Input-Output Differential

($V_O = 5.0\text{ V} - 5.2\text{ V}$)
 ($V_O = 12\text{ V} - 15\text{ V}$)

25 V
 30 V

Power Dissipation

Internally Limited

Operating Junction Temperature Range

LM120
 LM220
 LM320

Storage Temperature Range

Lead Temperature (Soldering, 10 seconds)

-55°C to +150°C
 -25°C to +150°C
 0°C to +125°C
 -65°C to +150°C
 +300°C

Part Number		LM120-5.0 LM220-5.0		LM320-5.0		LM120-5.2 LM220-5.2		LM320-5.2		LM120-12 LM220-12		LM320-12		LM120-15 LM220-15		LM320-15			
Input Voltage (unless otherwise noted)		-10 V		-10 V		-10.2 V		-10.2 V		-17 V		-17 V		-20 V		-20 V			
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
V_O	Output Voltage	-4.9	-5	-5.1	-4.8	-5	-5.2	-5.3	-5	-5.2	-5.4	-11.7	-12	-12.3	-11.6	-12	-12.4	-14.7	-15
	$P_D = P_{D(\text{MAX})}$	-4.8	-5	-5.2	-4.75	-5	-5.25	-5	-5.4	-4.95	-5.45	-11.5	-12.5	-11.4	-12.6	-14.5	-15.5	-14.4	-15.6
	$V_{IN} = -()\text{ V}$	(7 - 25)			(7 - 25)			(7 - 25)			(14 - 32)			(17 - 35)			(17 - 35)		
ΔV_O	Load Regulation (Note 2)	20	50		20	50		20	50		10	25		10	25		10	40	
	$T_J = 25^{\circ}\text{C}$	(5 - 500)			(5 - 500)			(5 - 500)			(5 - 200)			(5 - 200)			(5 - 200)		
	$V_{IN} = ()\text{ mA}$																		
	Line Regulation (Note 2)	50	75		50	100		50	75		30	80		30	80		30	80	
	$T_J = 25^{\circ}\text{C}$	(5 - 1500)			(5 - 1500)			(5 - 1500)			(5 - 1000)			(5 - 1000)			(5 - 1000)		
	$V_{IN} = ()\text{ mA}$																		
I_Q	Long Term Stability	5	50		5	50		5	50		15	120		15	120		15	150	
	Quiescent Current	1	2		1	2		1	2		2	4		2	4		2	4	
	$T_J = 25^{\circ}\text{C}$	(0.1 - 0.4)			(0.1 - 0.4)			(0.1 - 0.4)			(0.1 - 0.4)			(0.1 - 0.4)			(0.1 - 0.4)		
ΔI_Q	Quiescent Current Change	0.1	0.4		0.1	0.4		0.1	0.4		0.1	0.4		0.1	0.4		0.1	0.1	
	$I_O = 5\text{ mA} - I_{\text{MAX}}$																		
	$V_{IN} = -()\text{ V}$	(7 - 25)			(7 - 25)			(7 - 25)			(14 - 32)			(17 - 35)			(17 - 35)		
v_n	Output Noise Voltage $f = 10\text{ Hz} - 100\text{ kHz}$	150*			150*			150*			400			400			400		
θ_{JC}	Thermal Resistance, Junction-to-Case	15			15			15			15			15			15		
		3			3			3			3			3			3		

* $C_{LOAD} = 1\text{ }\mu\text{F}$

Note 1: Unless otherwise specified, these specifications apply. For the TO-5 package, $I_{\text{MAX}} = 0.2\text{ A}$ and $P_{\text{MAX}} = 2.0\text{ W}$. For the TO-3 package, $I_{\text{MAX}} = 1.0\text{ A}$ and $P_{\text{MAX}} = 20\text{ W}$. Although power dissipation is internally limited, electrical specifications apply only for power levels up to P_{MAX} . For calculations of junction temperature rise due to power dissipation, use a thermal resistance of 150°C/W for the TO-5 and 35°C/W for the TO-3. With an infinite heat sink, the thermal resistance is 15°C/W and 3°C/W respectively.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, pulse testing with a low duty cycle is used.

Input-Output Differential	Power Dissipation	Internally Limited
-25 V ($V_O = 5\text{ V} - 8\text{ V}$)	25 V	0°C to +125°C
-35 V ($V_O = 12\text{ V} - 18\text{ V}$)	30 V	-65°C to +150°C
-40 V ($V_O = 24\text{ V}$)	35 V	+230°C

$T_1 = 0^\circ\text{C}$ to $+125^\circ\text{C}$ unless noted

Part Number		LM320T-5.0												LM320T-5.2												LM320T-6.0												LM320T-8.0												LM320T-12												LM320T-15												LM320T-18												LM320T-24												Units
Input Voltage (unless otherwise noted)		-10 V				-10.2 V				-11 V				-13 V				-17 V				-20 V				-23 V				-29 V																																																																				
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max																																																																			
V _O	Output Voltage	-4.8	-5	-5.2	-5	-5.2	-5.4	-5.75	-6	-6.25	-7	-8	-8.3	-11.5	-12	-12.5	-14.4	-15	-15.6	-17.3	-18	-18.7	-23	-24	-25								V																																																																	
	P _D = 15 W I _O = 5 - 1000 mA V _{IN} = -() V	-4.75		-5.25	-4.95		-5.45	-5.7		-6.3	-7.6		-8.4	-11.4		-12.6	-14.3		-15.7	-17.1		-18.9	-22.8	-25.2																																																																										
		(7.5 - 25)		(7.5 - 25)	(7.5 - 25)		(7.5 - 25)	(8.5 - 25)		(8.5 - 25)	(10.5 - 25)		(10.5 - 25)	(14.5 - 32)		(14.5 - 32)	(17.5 - 35)		(17.5 - 35)	(21 - 35)		(21 - 35)	(27 - 40)																																																																											
ΔV _O	Line Regulation	10	40	10	40	10	40	12	40	15	40	15	40	4	24	4	24	5	30	8	36	12	50										mV																																																																	
	(Note 2)	(7.5 - 25)		(7.5 - 25)	(7.5 - 25)		(7.5 - 25)	(8.5 - 25)		(8.5 - 25)	(10.5 - 25)		(10.5 - 25)	(14.5 - 32)		(14.5 - 32)	(17.5 - 35)		(17.5 - 35)	(21 - 35)		(21 - 35)	(27 - 35)																																																																											
	Load Regulation	20	120	20	120	20	120	20	120	20	120	20	120	40	120	40	120	50	120	50	120	50	120	50	120																																																																									
Long Term Stability	(Note 2)	(5 - 1500)		(5 - 1500)	(5 - 1500)		(5 - 1500)	(5 - 1500)		(5 - 1500)	(5 - 1500)		(5 - 1500)	(5 - 1000)		(5 - 1000)	(5 - 1000)		(5 - 1000)	(5 - 1000)		(5 - 1000)	(5 - 1000)									mV																																																																		
	Quiescent Current	10	10	10	10	10	10	12	10	15	15	15	15	25	25	25	30	30	30	35	35	35	50	50	1000 hrs								mV																																																																	
	T _J = 25°C	1	3	1	3	1	3	1	3	1	3	1	3	2	4	2	4	2	4	2	4	2	4	2	4								1000 hrs																																																																	
ΔI _Q	Quiescent Current Change	T _J = 25°C	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5									mV																																																																	
		I _O = 5 - 1000 mA	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1	0.5									mV																																																																	
		V _{IN} = -() V	(7.5 - 25)		(7.5 - 25)	(7.5 - 25)		(7.5 - 25)	(8.5 - 25)		(8.5 - 25)	(10.5 - 25)		(10.5 - 25)	(14.5 - 32)		(14.5 - 32)	(17.5 - 35)		(17.5 - 35)	(21 - 35)		(21 - 35)	(27 - 35)									mV																																																																	
v _n	Output Noise Voltage	150	150	150	150	150	150	180	180	250	250	250	250	400	400	400	400	400	400	500	500	700	700	700									μV																																																																	
	T _J = 25°C f = 10 Hz - 100 kHz	(7.5 - 25)		(7.5 - 25)	(7.5 - 25)		(7.5 - 25)	(8.5 - 25)		(8.5 - 25)	(10.5 - 25)		(10.5 - 25)	(14.5 - 32)		(14.5 - 32)	(17.5 - 35)		(17.5 - 35)	(21 - 35)		(21 - 35)	(27 - 35)									μV																																																																		
ρ _{JC}	Thermal Resistance, Junction-to-Case	5		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5									°C/W																																																																	

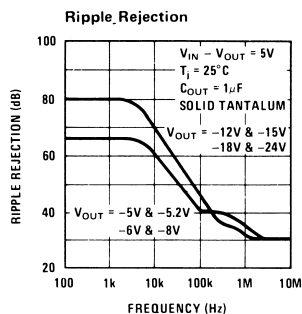
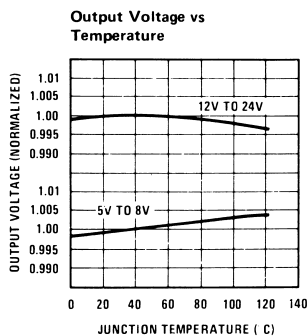
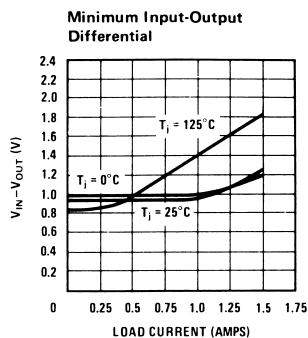
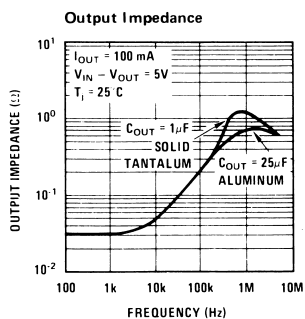
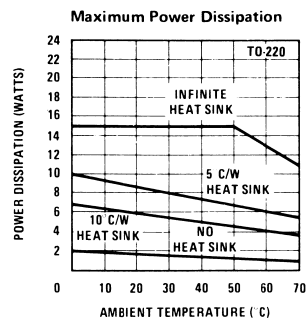
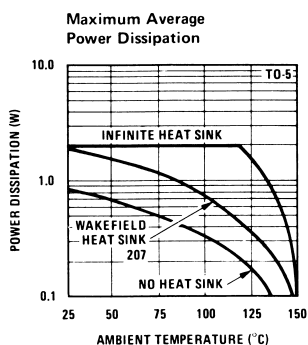
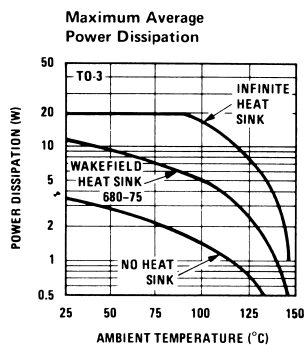
Note 1: Unless otherwise specified, these specifications apply: For the TO-5 package, $I_{MAX} = 0.2$ A and $P_{MAX} = 2.0$ W. For the TO-3 package, $I_{MAX} = 1.0$ A and $P_{MAX} = 20$ W. Although power dissipation is in-

Note 1: Unless otherwise specified, these specifications apply: For the TO-3 package, $I_{MAX} = 0.2\text{ A}$ and $P_{MAX} = 2.0\text{ W}$. For the TO-5 package, $I_{MAX} = 1.0\text{ A}$ and $P_{MAX} = 20\text{ W}$. Although power dissipation is certainly limited, electrical specifications apply only for power revers up to P_{MAX} . For calculations of junction temperature rise due to power dissipation, use a thermal resistance of 111°C/W for the TO-3 package.

certainly limited, electrical specifications apply only for power levels up to T_{MAX} . For calculations of junction temperature rise due to power dissipation, use a thermal resistance of 150°C/W for the TO-18 and 35°C/W for the TO-3. With an infinite heat sink, the thermal resistance is 15°C/W and 3°C/W respectively.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, pulse testing with a low duty cycle is used.

typical performance characteristics





Voltage Regulators

LM123/LM223/LM323 3 amp-5 volt positive regulator general description

These three-terminal positive regulators have a preset 5V output and a load driving capability of 3 amps. New circuit design and processing techniques are used to provide the high output current without sacrificing the regulation characteristics of lower current devices.

The 3 amp regulator is virtually blowout proof. Current limiting, power limiting, and thermal shutdown provide the same high level of reliability obtained with these techniques in the LM109 1 amp regulator.

No external components are required for operation of the LM123. If the device is more than 4 inches from the filter capacitor, however, a $1\mu\text{F}$ solid tantalum capacitor should be used on the input. A $0.1\mu\text{F}$ or larger capacitor may be used on the output to reduce load transient spikes created by fast switching digital logic, or to swamp out stray load capacitance.

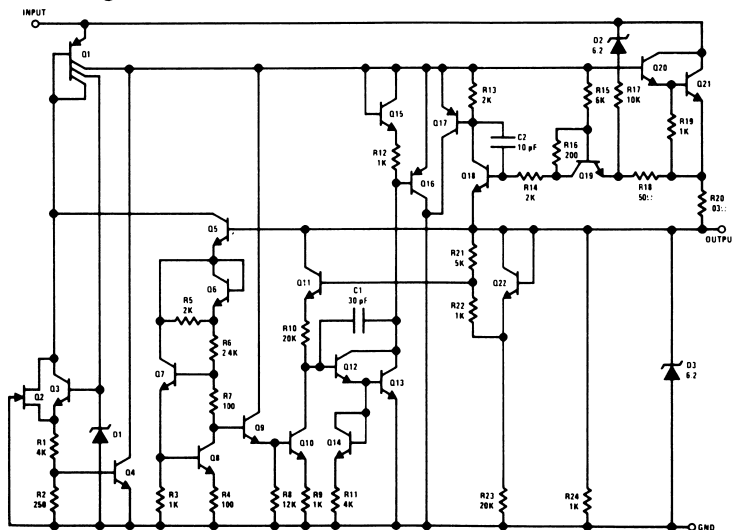
An overall worst case specification for the combined effects of input voltage, load currents, ambient temperature, and power dissipation ensure that the LM123 will perform satisfactorily as a system element.

Operation is guaranteed over the junction temperature range -55°C to $+150^{\circ}\text{C}$. An electrically identical LM223 operates from -25°C to $+150^{\circ}\text{C}$ and the LM323 is specified from 0°C to $+125^{\circ}\text{C}$ junction temperature. A hermetic TO-3 package is used for high reliability and low thermal resistance.

features

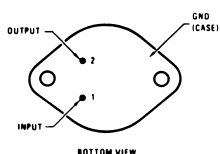
- 3 amp output current
- Internal current and thermal limiting
- 0.01Ω typical output impedance
- 7.5 minimum input voltage
- 30W power dissipation

schematic diagram



connection diagram

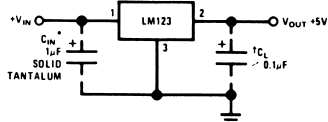
TO-3 (K)



Order Number LM123K,
LM223K or LM323K

typical applications

Basic 3 Amp Regulator



*Required if LM123 is more than 4" from filter capacitor.

†Regulator is stable with no load capacitor into resistive loads.

absolute maximum ratings

Input Voltage	20 V
Power Dissipation	Internally Limited
Operating Junction Temperature Range	
LM123	-55°C to +150°C
LM223	-25°C to +150°C
LM323	0°C to +125°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 10 sec)	300°C

electrical characteristics (Note 1)

PARAMETER	CONDITIONS	LM123/LM223			LM323			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Output Voltage	$T_J = 25^\circ\text{C}$ $V_{IN} = 7.5\text{ V}, I_{OUT} = 0$	4.7	5	5.3	4.8	5	5.2	V
Output Voltage	$7.5\text{ V} \leq V_{IN} \leq 15\text{ V}$ $0 \leq I_{OUT} \leq 3\text{ A}, P \leq 30\text{ W}$	4.6		5.4	4.75		5.25	V
Line Regulation (Note 3)	$T_J = 25^\circ\text{C}$ $7.5\text{ V} \leq V_{IN} \leq 15\text{ V}$		5	25		5	25	mV
Load Regulation (Note 3)	$T_J = 25^\circ\text{C}, V_{IN} = 7.5\text{ V}$ $0 \leq I_{OUT} \leq 3\text{ A}$		25	100		25	100	mV
Quiescent Current	$7.5\text{ V} \leq V_{IN} \leq 15\text{ V}$ $0 \leq I_{OUT} \leq 3\text{ A}$		12	20		12	20	mA
Output Noise Voltage	$T_J = 25^\circ\text{C}$ $10\text{ Hz} \leq f \leq 100\text{ kHz}$		40			40		μV_{rms}
Short Circuit Current Limit	$T_J = 25^\circ\text{C}, V_{IN} = 15\text{ V}$ $V_{IN} = 7.5\text{ V}$	3	4.5		3	4.5		A
		4	5		4	5		A
Long Term Stability				35			35	mV
Thermal Resistance, Junction to Case (Note 2)			2			2		$^\circ\text{C/W}$

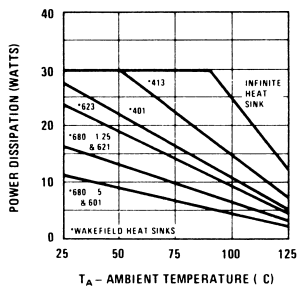
Note 1: Unless otherwise noted, specifications apply for $-55^\circ\text{C} \leq T_J \leq +150^\circ\text{C}$ for the LM123, $-25^\circ\text{C} \leq T_J \leq +150^\circ\text{C}$ for the LM223, and $0^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ for the LM323. Although power dissipation is internally limited, specifications apply only for $P \leq 30\text{ W}$.

Note 2: Without a heat sink, the thermal resistance of the TO-3 package is about 35°C/W . With a heat sink, the effective thermal resistance can only approach the specified values of 2°C/W , depending on the efficiency of the heat sink.

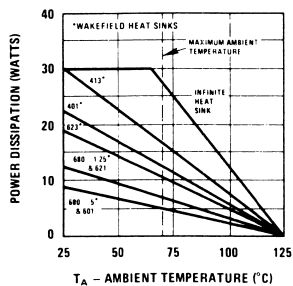
Note 3: Load and line regulation are specified at constant junction temperature. Pulse testing is required with a pulse width $\leq 1\text{ ms}$ and a duty cycle $\leq 5\%$.

typical performance characteristics

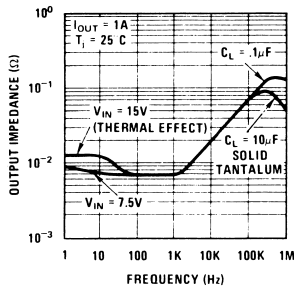
**Maximum Average Power
Dissipation For LM123;
LM223**



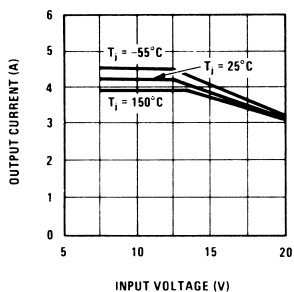
**Maximum Average Power
Dissipation For LM323**



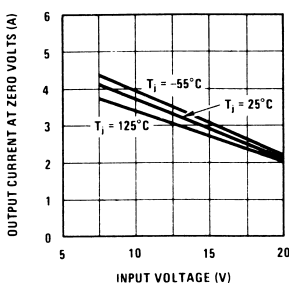
Output Impedance



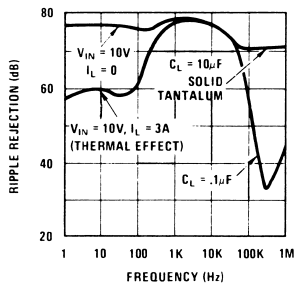
Peak Available Output Current



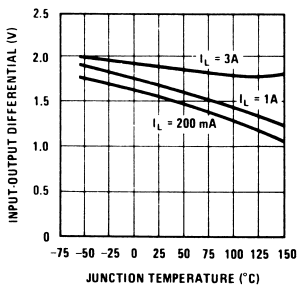
Short Circuit Current



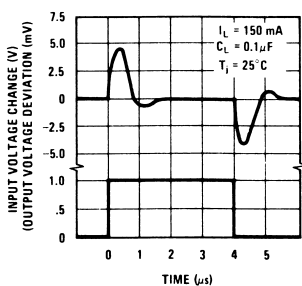
Ripple Rejection



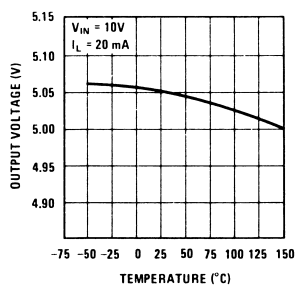
Dropout Voltage



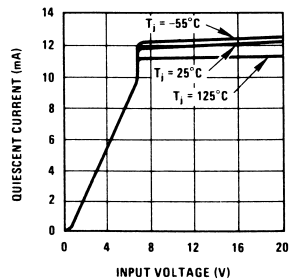
Line Transient Response



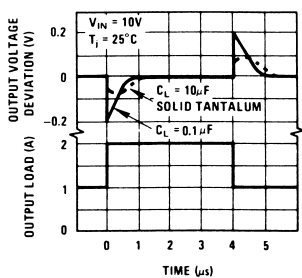
Output Voltage



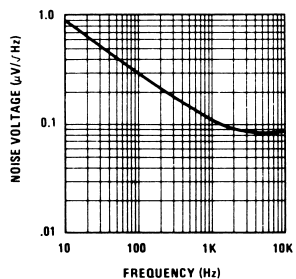
Quiescent Current



Load Transient Response



Output Noise Voltage





Voltage Regulators

LM125/LM225/LM325/LM325A voltage regulators LM126/LM226/LM326 LM127/LM227/LM327

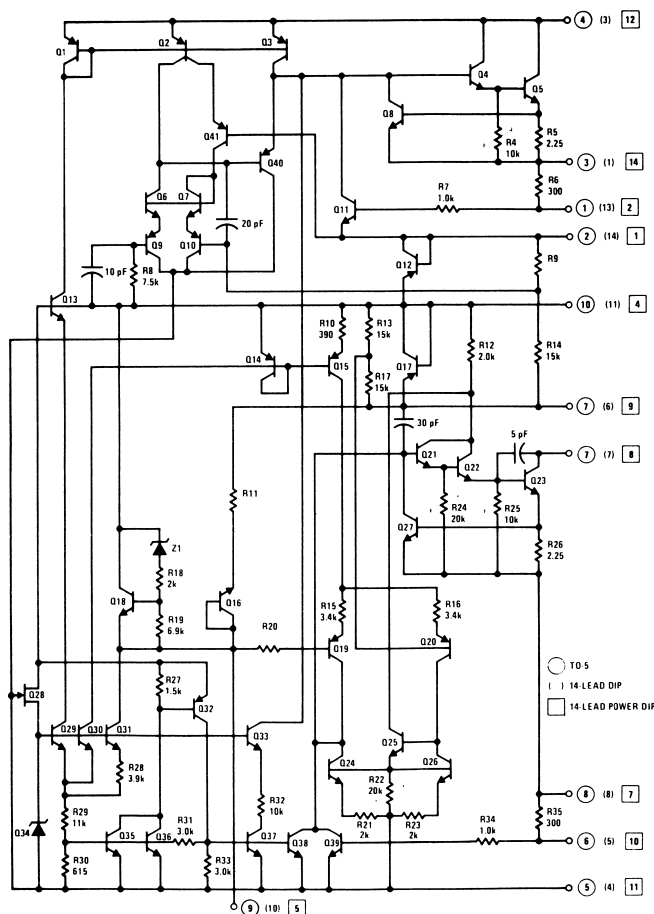
general description

These are dual polarity tracking regulators designed to provide balanced positive and negative output voltages at current up to 100 mA, the devices are set for ± 15 V, ± 12 V and ± 5 , -12 V outputs respectively. Input voltages up to ± 30 V can be used and there is provision for adjustable current limiting. These devices are available in three package types to accommodate various power requirements and temperature ranges.

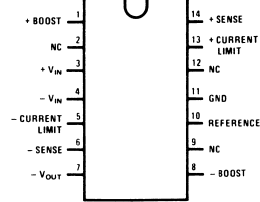
features

- ± 15 V, ± 12 V and ± 5 , -12 V tracking outputs
- Output currents to 100 mA
- Output voltages balanced to within 1% (LM125, LM126, LM127, LM325A)
- Line and load regulation of 0.06%
- Internal thermal overload protection
- Standby current drain of 3 mA
- Externally adjustable current limit
- Internal current limit

schematic and connection diagrams

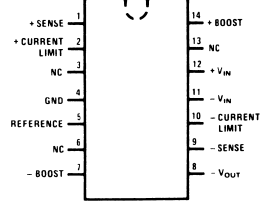


Dual-In-Line Package (N)



TOP VIEW
Order Number LM325AN, LM325N,
LM326N, or LM327N

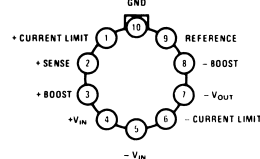
Dual-In-Line Power Package (S)



TOP VIEW
Order Number LM325AS, LM325S,
LM326S, or LM327S

Note: S Package heat sink is connected to $-V_{IN}$.

TO-100



TOP VIEW
Order Number
LM125H, LM225H, LM325H,
LM126H, LM226H, LM326H,
LM127H, LM227H, or LM327H

absolute maximum ratings

Operating Temperature Range

LM125, 126, 127

LM225, 226, 227

LM325, 325A, 326, 327

Storage Temperature Range

Lead Temperature (Soldering, 10 seconds)

-55°C to +125°C

-25°C to +85°C

0°C to +70°C

-65°C to +150°C

+300°C

Input Voltage

Forced V_{O+} (Min) (Note 1)

Forced V_{O-} (Max) (Note 1)

Power Dissipation (Note 2)

Output Short-Circuit Duration (Note 3)

±30 V

-0.5 V

+0.5 V

Internally Limited

Indefinite

electrical characteristics

(Note 2) unless noted

$T_J = -55^\circ\text{C}$ to $+150^\circ\text{C}$ LM100 series

$T_J = -55^\circ\text{C}$ to $+150^\circ\text{C}$ LM200 series

0°C to $+125^\circ\text{C}$ LM300 series

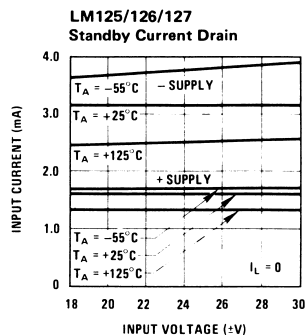
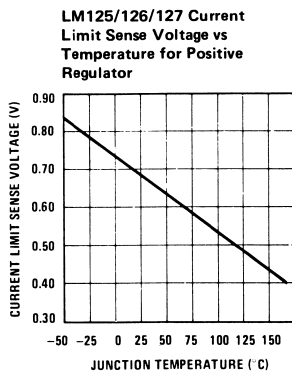
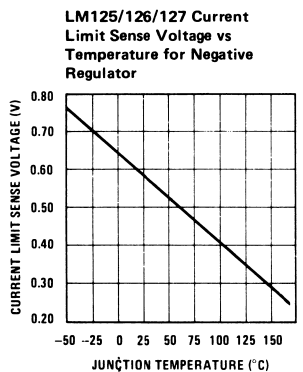
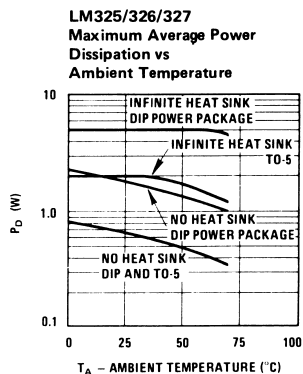
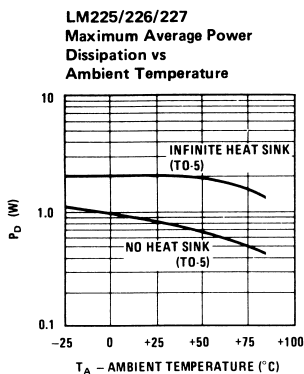
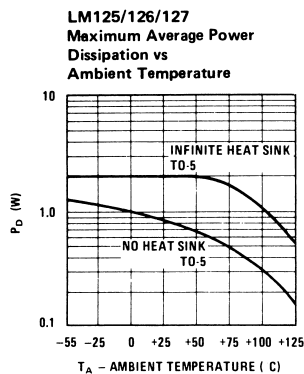
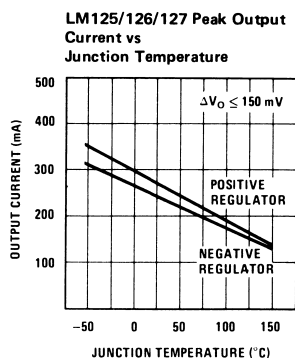
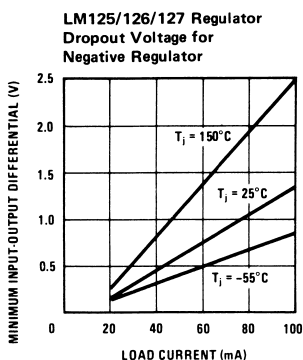
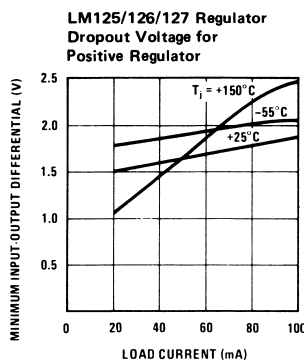
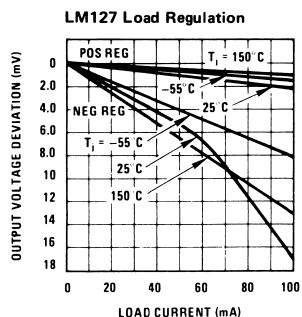
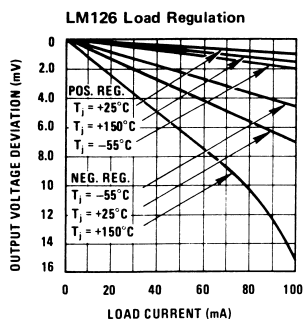
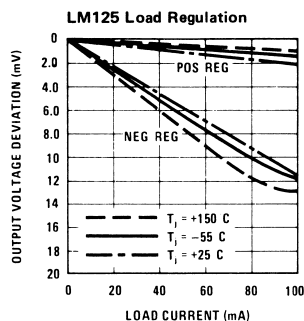
Part Number		LM125		LM225		LM325		LM325A		LM126		LM226		LM326		LM127 LM227 LM327		Units		
Input Voltage (unless otherwise noted)		±20 V		±20 V		±20 V		±20 V		±20 V		±20 V		±20 V		±20 V				
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V _O Output Voltage	T _J = 25°C	14.8	15	15.2	14.8	15	15.5	14.8	15	15.2	11.3	12	12.2	11.8	12	12.5	11.5	12	12.5	
	P _D = P _{D(MAX)} I _O ≤ 50 mA	14.65		15.35	14.57		15.43	14.27		15.73	14.65		15.35	11.68		12.38	11.32		12.68	
	V _{IN} = () V	(18 - 30)				(18 - 30)				(18 - 30)				(15 - 30)			(15 - 30)			(18 - 30) - (15 - 30)
ΔV _O Load Regulation	V _{IN} = ±30 V	3	10		3	10		3	10		3	10		3	10		3	10		
	T _J = 25°C																			
	I _O = 0 - 50 mA	5	10		5	10		5	10		5	10		5	10		5	10		
Line Regulation		4	20		4	20		4	20		4	20		4	20		4	20		
	T _J = 25°C	7	20		7	20		7	20		7	20		7	20		7	20		
	I _O = 20 mA	2	10		2	10		2	10		2	10		2	10		2	10		
Long Term Stability	V _{IN} = () V	2	20		2	20		2	20		2	20		2	20		2	20		
	T _J = 25°C	(18 - 30)			(18 - 30)			(18 - 30)			(15 - 30)			(15 - 30)			(18 - 30) - (15 - 30)			
		0.2			0.2			0.2			0.2			0.2			0.2			
I _Q Quiescent Current	T _J = 25°C	1.75	3		1.75	3		1.75	3		1.75	3		1.75	3		1.75	3		
	NEG	3.1	5		3.1	5		3.1	5		3.1	5		3.1	5		3.1	5		
Output Balance	T _J = 25°C	150			150			300			125			125			250			
ΔV _O Temp Stability		0.3			0.3			0.3			0.3			0.3			0.3			
v _n Output Noise Voltage	T _J = 25°C f = 100 Hz - 10 kHz	150			150			150			150			150			160			
	NEG	150			150			150			150			150			100			
Short Circuit Current Limit	T _J = 25°C	260			260			260			260			260			260			
Dropout Voltage V _{IN} - V _{OUT}	T _J = 25°C	2			2			2			2			2			2			

Note 1: See Definition of Terms.

Note 2: Minimum $V_{IN} - V_O = 2$ V. $I_{MAX} = 100$ mA, $P_{MAX} = 2.0$ W for the TO-5 H package. $I_{MAX} = 100$ mA, $P_{MAX} = 1.0$ W for the DIP N package.

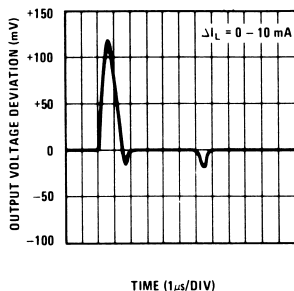
Note 3: If the junction temperature exceeds 150°C the output short circuit duration is 60 seconds.

typical performance characteristics ($V_{IN} = \pm 20V$, $I_L = 0$ mA, $T_J = 25^\circ C$, unless otherwise noted.)

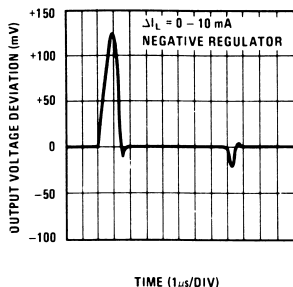


typical performance characteristics (con't)

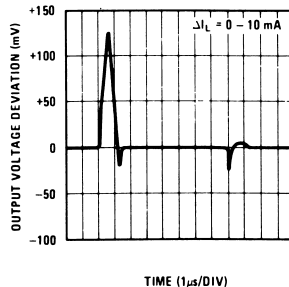
LM125
Load Transient Response
for Negative Regulator



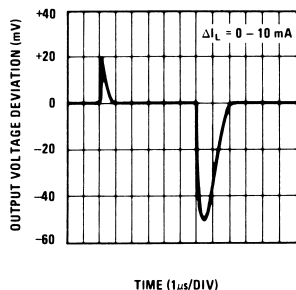
LM126
Load Transient Response



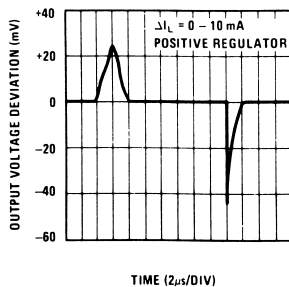
LM127
Load Transient Response
for Negative Regulator



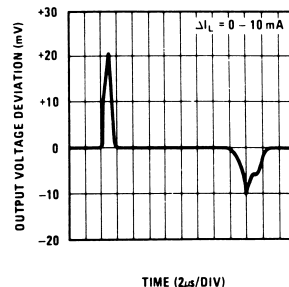
LM125
Load Transient Response
for Positive Regulator



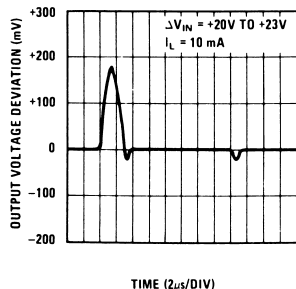
LM126
Load Transient Response



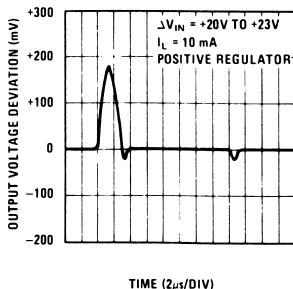
LM127
Load Transient Response
for Positive Regulator



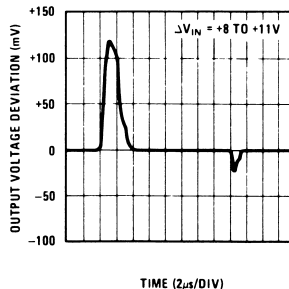
LM125
Line Transient Response
for Positive Regulator



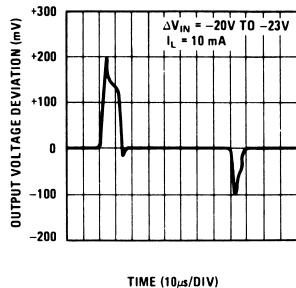
LM126
Line Transient Response



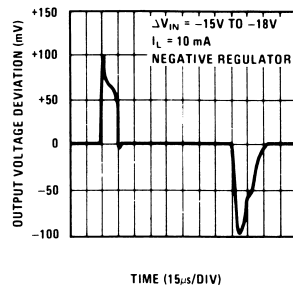
LM127
Line Transient Response
for Positive Regulator



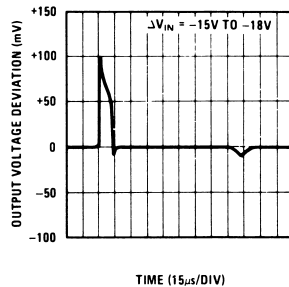
LM125
Line Transient Response
for Negative Regulator



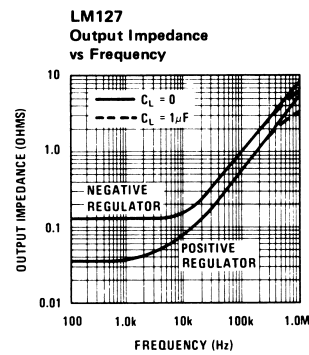
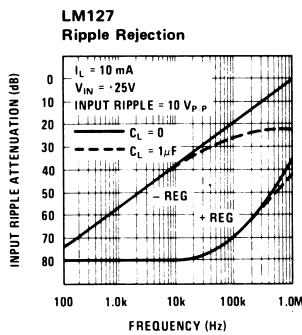
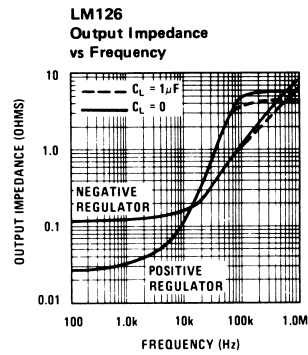
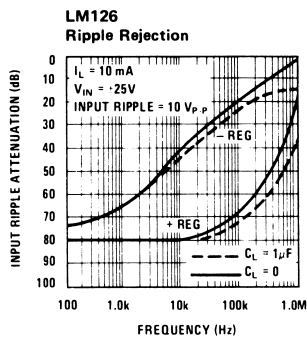
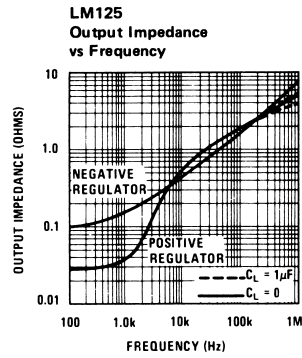
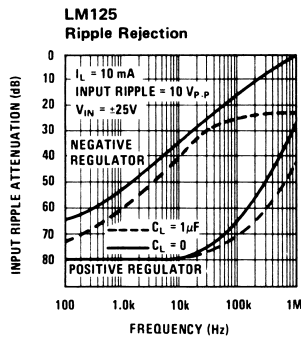
LM126
Line Transient Response



LM127
Line Transient Response
for Negative Regulator



typical performance characteristics (con't)





Voltage Regulators

LM340/LM340-R series voltage regulators

general description

The LM340-XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM340-XX series is available in two power packages. Both the plastic TO-220 and metal TO-3 packages allow these regulators to deliver over 1.0A if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expended to make the LM340-XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

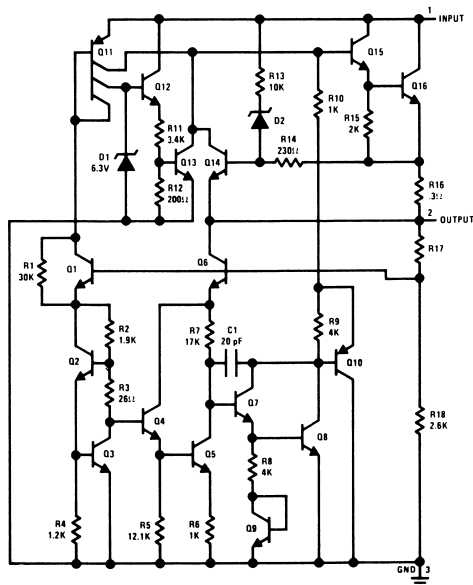
features

- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-220 and metal TO-3 packages

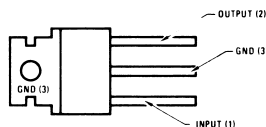
voltage range

LM340-5/340-5.0R	5V	LM340-15/340-15R	15V
LM340-6/340-6.0R	6V	LM340-18/340-18R	18V
LM340-8/340-8.0R	8V	LM340-24/340-24R	24V
LM340-12/340-12R	12V		

schematic and connection diagrams



TO-220 (T)

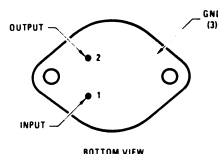


TOP VIEW

Order Numbers

LM340T-5.0	LM340T-15	LM340T-5.0R	LM340T-15R
LM340T-6.0	LM340T-18	LM340T-6.0R	LM340T-18R
LM340T-8.0	LM340T-24	LM340T-8.0R	LM340T-24R
LM340T-12		LM340T-12R	

TO-3 (K)



BOTTOM VIEW

Order Numbers

LM340K-5	LM340K-15	LM340K-5.0R	LM340K-15R
LM340K-6	LM340K-18	LM340K-6.0R	LM340K-18R
LM340K-8	LM340K-24	LM340K-8.0R	LM340K-24R
LM340K-12		LM340K-12R	

absolute maximum ratings

Input Voltage
($V_O = 5\text{ V} - 18\text{ V}$)
($V_O = 24\text{ V}$)

Internal Power Dissipation (Note 1)
Operating Temperature Range

Maximum Junction Temperature
TO-3 package
TO-220 package
Storage Temperature Range
Lead Temperature (Soldering, 10 seconds)
TO-3 package
TO-220 package

+150°C
+150°C
-65°C to +150°C
+300°C
+230°C

electrical characteristics (unless noted)

$T_A = 0^\circ\text{C}$ to $+70^\circ\text{C}$

$I_O = 500\text{ mA}$

Part Number		LM340-5.0		LM340-6.0		LM340-8.0		LM340-12		LM340-15		LM340-18		LM340-24		Units
Input Voltage (unless otherwise noted)		10 V		11 V		14 V		19 V		23 V		27 V		33 V		
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
V _O Output Voltage	T _J = 25°C	4.8	5	5.2	5.75	6	6.25	7.7	8	8.3	11.5	12	12.5	14.4	15	15.6
	P _D ≤ 15 W	4.75		5.25	5.7	6.3	6.3	7.6	8.4	8.4	11.4		12.6	14.25	15.75	17.1
	V _{IN} = () V	(7 - 20)		(8 - 21)		(10.5 - 23)		(14.5 - 27)		(17.5 - 30)		(21 - 33)		(27 - 38)		
ΔV _O Line Regulation	T _J = 25°C			50		60		80		120		150		180		240
	V _{IN} = () V						120	160		240		300		360		480
Load Regulation	T _J = 25°C															
	I _O = () mA			100		120		160		240		300		360		480
Long Term Stability	T _J = 25°C			20		24		32		48		60		72		96
	I _O = () mA			7		10		10		10		10		10		10
I _Q Quiescent Current	T _J = 25°C															
	I _O = () mA			0.5		0.5		0.5		0.5		0.5		0.5		0.5
ΔI _Q Quiescent Current Change	T _J = 25°C															
	V _{IN} = () V			1.3		1.3		1.3		1.3		1.3		1.3		1.3
v _n Output Noise Voltage	T _J = 25°C															
	f = 10 Hz – 100 kHz			40		45		52		75		90		110		170
ΔV _{IN} / ΔV _{OUT} Ripple Rejection	f = 120 Hz			60		57		55		52		50		48		44
	T _J = 25°C			2		2		2		2		2		2		2
Min Dropout Voltage V _{IN} - V _{OUT}	T _J = 25°C															

Note 1: Thermal resistance without a heat sink for junction to case temperature is 4°C/W for the TO-3 package and 6°C/W for the TO-220 package. Thermal resistance for case to ambient temperature is 35°C/W for the TO-3 package and 50°C/W for the TO-220 package.

absolute maximum ratings

Input Voltage
($V_O = 5\text{ V} - 18\text{ V}$)
($V_O = 24\text{ V}$)

Internal Power Dissipation (Note 1)
Operating Temperature Range

35 V
Maximum Junction Temperature
TO-3 package
TO-220 package
Storage Temperature Range
Lead Temperature (Soldering, 10 seconds)
TO-3 package
TO-220 package

+150°C
+150°C
-65°C to +150°C
+300°C
+230°C

electrical characteristics (unless noted)

$T_A = 0^\circ\text{C to } +70^\circ\text{C}$

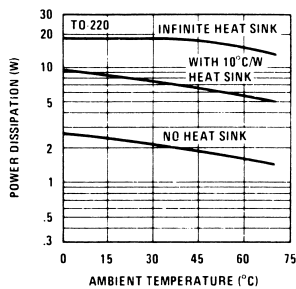
$I_O = 500\text{ mA}$

Part Number		LM340-5.0R		LM340-6.0R		LM340-8.0R		LM340-12R		LM340-15R		LM340-18R		LM340-24R		Units
Input Voltage (unless otherwise noted)		10 V		11 V		14 V		19 V		23 V		27 V		33 V		
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
V _O Output Voltage	T _J = 25°C	4.6	5	5.4	5.5	6	6.5	7.36	8	8.64	11	12	13	13.8	15	16.2
	P _D ≤ 15 W I _O = 5 - 1000 mA	4.5		5.5	5.4	6.6	7.2	8.8			10.8		13.2	13.5	16.5	19.8
	V _{IN} = () V	(7.7 - 20)			(8.8 - 21)			(11 - 23)		(15.3 - 27)		(18.6 - 30)		(22 - 33)		(28.5 - 38)
ΔV _O Line Regulation	T _J = 25°C			75			80			110			160			240
	V _{IN} = () V			150			160			210			320			480
Load Regulation	T _J = 25°C			140			160			210			320			480
	I _O = () mA	(7.4 - 25)			(8.5 - 25)			(10.7 - 25)		(15 - 30)		(18.2 - 30)		(27.4 - 33)		(28 - 38)
Long Term Stability	T _J = 25°C		15			18		24		36		45		54		72
	I _O = () mA	(5 - 1500)			(5 - 1500)			(5 - 1500)		(5 - 1500)		(5 - 1500)		(5 - 1000)		(5 - 1000)
I _Q Quiescent Current	T _J = 25°C		8	12		8	12	8	12	8	12	8	12	8	12	8
	I _O = () mA	(5 - 1500)			(5 - 1500)			(5 - 1500)		(5 - 1500)		(5 - 1500)		(5 - 1000)		(5 - 1000)
ΔI _Q Quiescent Current Change	T _J = 25°C		0.4			0.4		0.4		0.4		0.4		0.4		0.4
	V _{IN} = () V	(7.7 - 25)			(8.8 - 25)			(11 - 25)		(15.3 - 30)		(18.6 - 30)		(22 - 33)		(28.5 - 38)
v _n Output Noise Voltage	T _J = 25°C		50			55		62		85		100		120		180
	f = 10 Hz - 100 kHz															
ΔV _{IN} / ΔV _{OUT} Ripple Rejection	f = 120 Hz		58			55		53		50		48		46		42
	T _J = 25°C		2			2		2		2		2		2		2
Min Dropout Voltage V _{IN} - V _{OUT}																

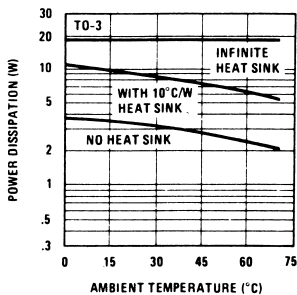
Note 1: Thermal resistance without a heat sink for junction to case temperature is 4°C/W for the TO-3 package and 6°C/W for the TO-220 package. Thermal resistance for case to ambient temperature is 35°C/W for the TO-3 package and 50°C/W for the TO-220 package.

typical performance characteristics

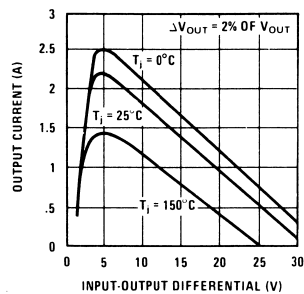
Maximum Average Power Dissipation



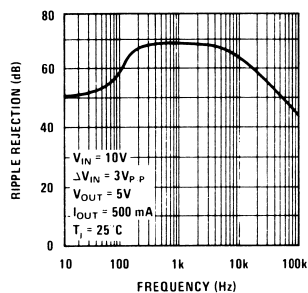
Maximum Average Power Dissipation



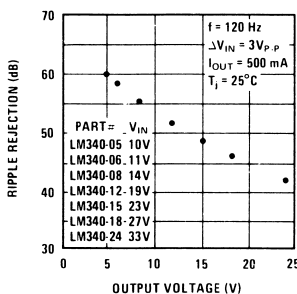
Peak Output Current



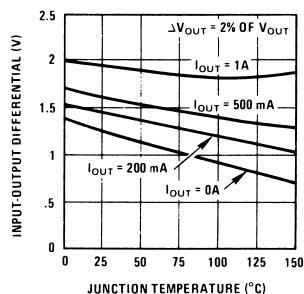
Ripple Rejection



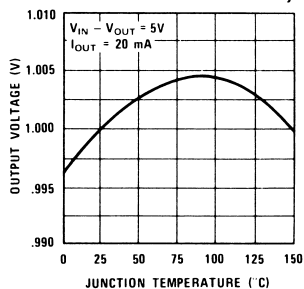
Ripple Rejection



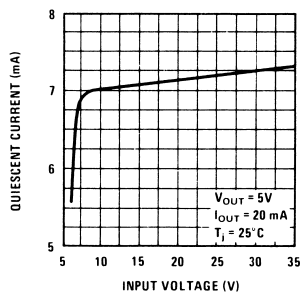
Dropout Voltage



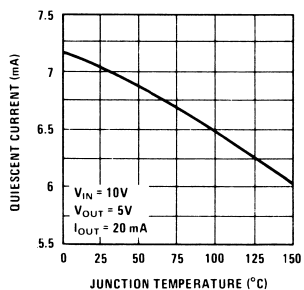
Output Voltage (Normalized to 1V at 25 $^{\circ}\text{C}$ T_j)



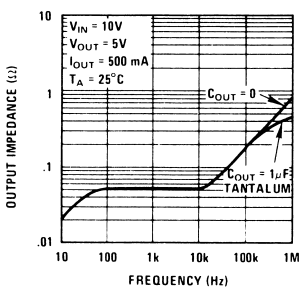
Quiescent Current



Quiescent Current



Output Impedance





Voltage Regulators

LM341 series three terminal positive regulators

general description

The LM341-XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM341-XX series is available in the plastic TO-202 package. This package allows these regulators to deliver over 0.5A if adequate heat sinking is provided. Even with over 0.5A of output current available the regulators are essentially blow-out proof. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expended to make the LM341-XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

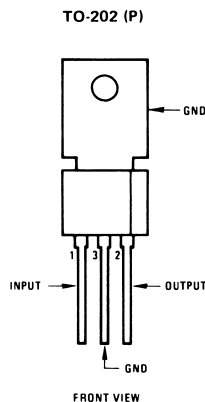
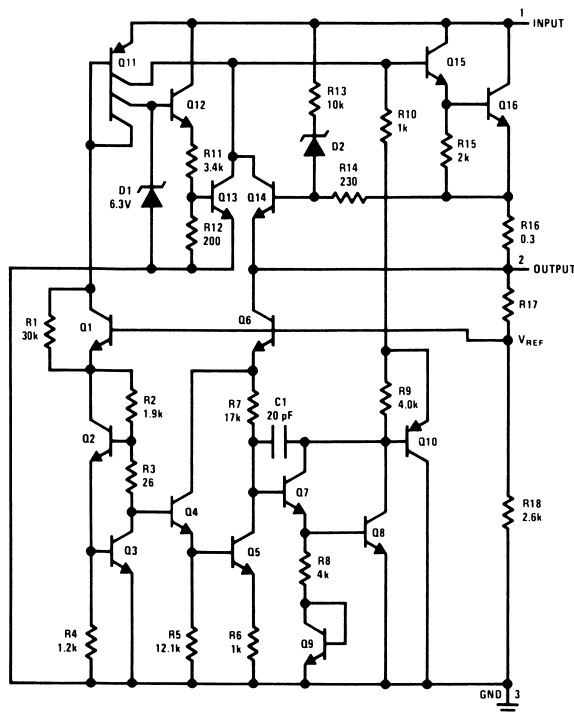
features

- Output current in excess of 0.5A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-202 package

voltage range

LM341-5.0	5V	LM341-15	15V
LM341-6.0	6V	LM341-18	18V
LM341-8.0	8V	LM341-24	24V
LM341-12	12V		

schematic and connection diagrams



Order Numbers

LM341P-5.0	LM341P-15
LM341P-6.0	LM341P-18
LM341P-8.0	LM341P-24
LM341P-12	

See Package 37

electrical characteristics

(unless noted)
 $T_A = 0^\circ\text{C to } 70^\circ\text{C}$
 $I_O = 500\text{ mA}$

absolute maximum ratings

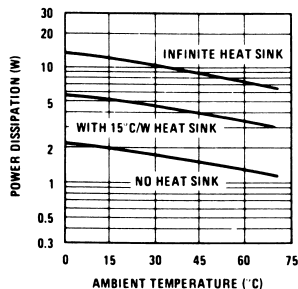
Input Voltage
 $(V_O = 5\text{ V} - 18\text{ V})$
 $(V_O = 24\text{ V})$
 35 V
 40 V
 Internally Limited
 0°C to +70°C
 +150°C
 -65°C to +150°C
 +230°C
 Internal Power Dissipation (Note 1)
 Operating Temperature Range
 Maximum Junction Temperature
 Storage Temperature Range
 Lead Temperature (Soldering, 10 seconds)

Part Number		LM341P-5.0														LM341P-6.0				LM341P-8.0				LM341P-12				LM341P-15				LM341P-18				LM341P-24			
Input Voltage (unless otherwise noted)		10 V				11 V				14 V				19 V				23 V				27 V				33 V													
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max								
V _O	Output Voltage T _J = 25°C P _D ≤ 7.5 W I _O = 5 – 500 mA V _{IN} = () V	4.8	5	5.2	5.75	6	6.25	7.7	8	8.3	11.5	12	12.5	14.4	15	15.6	17.3	18	18.7	23	24	25																	
		4.75		5.25	5.7	6.3	6.3	7.6	8.4	8.4	11.4	12.6	14.25	15.75	17.1	18.9	22.8	25.2																					
		(7.5 - 20)		(8.6 - 21)		(10.6 - 23)		(14.8 - 27)		(18 - 30)		(21 - 33)		(27.3 - 38)																									
ΔV _O	Line Regulation T _J = 25°C I _O = 100 mA V _{IN} = () V I _O = 500 mA			50			60			80			120			150			180			240																	
					100			120			160			240			300			360			480																
Load Regulation	T _J = 25°C I _O = 5 – 500 mA																																						
I _Q	Long Term Stability T _J = 25°C																																						
				20			24			32			48			60			72			96																	
Quiescent Current	T _J = 25°C	7	10	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10	7	10							
				0.5			0.5			0.5			0.5			0.5			0.5			0.5			0.5														
				1			1			1			1			1			1			1			1			1											
ΔI _Q	Quiescent Current Change T _J = 25°C I _O = 5 – 500 mA V _{IN} = () V																																						
v _n	Output Noise Voltage T _J = 25°C f = 10 Hz – 100 kHz f = 120 Hz	40			45			52			75			90			100			170																			
				60			57			55			52			50			48			44																	
Min Dropout Voltage V _{IN} – V _{OUT}	T _J = 25°C	2			2			2			2			2			2			2																			

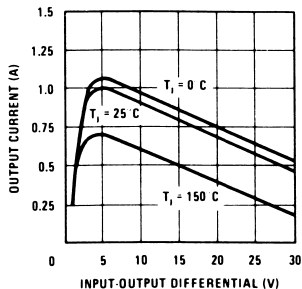
Note 1: Thermal resistance without a heat sink for junction to case temperature is 12°C/W for the TO-202 package. Thermal resistance for case to ambient temperature is 70°C/W for the TO-202 package.

typical performance characteristics

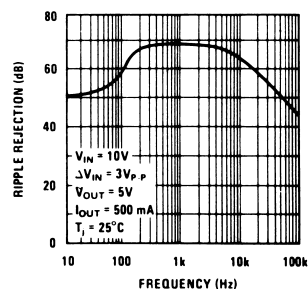
Maximum Average Power Dissipation



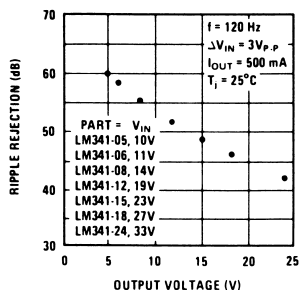
Peak Output Current



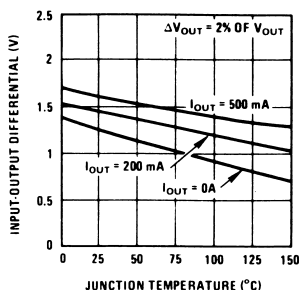
Ripple Rejection



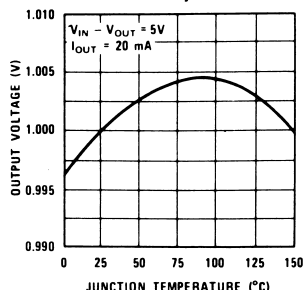
Ripple Rejection



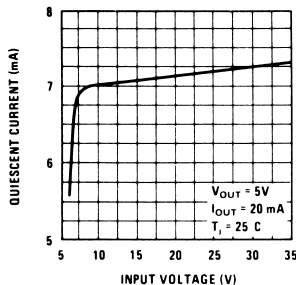
Dropout Voltage



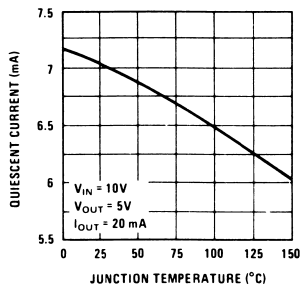
Output Voltage (Normalized to 1V at 25°C T_j)



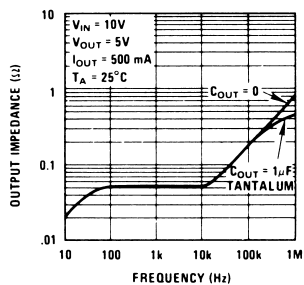
Quiescent Current



Quiescent Current



Output Impedance





Voltage Regulators

LM342 series three terminal positive regulators general description

The LM342-XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM342-XX series is available in the plastic TO-202 package. This package allows these regulators to deliver over 0.2A if adequate heat sinking is provided. Even with over 0.2A of output current available the regulators are essentially blow-out proof. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expended to make the LM342-XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

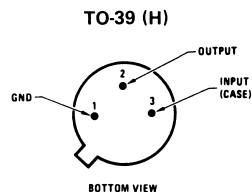
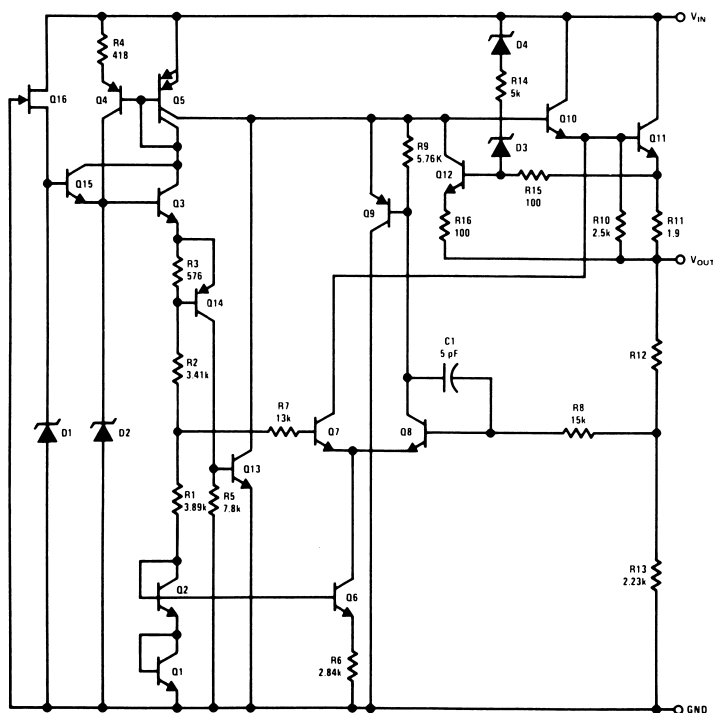
features

- Output current in excess of 0.2A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-202 package

voltage range

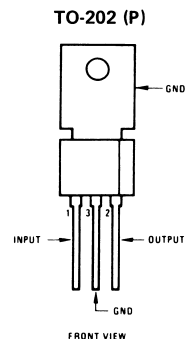
LM342-5.0	5V	LM342-12	12V
LM342-6.0	6V	LM342-15	15V
LM342-8.0	8V	LM342-18	18V
LM342-10	10V	LM342-24	24V

schematic and connection diagrams



Order Numbers

LM342H-5	LM342H-12
LM342H-6	LM342H-15
LM342H-8	LM342H-18
LM342H-10	LM342H-24



Order Numbers

LM342P-5	LM342P-12
LM342P-6	LM342P-15
LM342P-8	LM342P-18
LM342P-10	LM342P-24

absolute maximum ratings

Internal Power Dissipation (Note 1)
Operating Temperature Range
Maximum Junction Temperature
Storage Temperature Range

Internally Limited
0°C to +70°C
+150°C

Metal Can Package (H)
Molded TO-202 Package (P)
Lead Temperature (Soldering, 10 seconds)

-65°C to +150°C
-55°C to +150°C
+300°C

Input Voltage
(V_O = 5 V - 8 V)
(V_O = 10 V - 18 V)
(V_O = 24 V)

30 V
35 V
40 V

electrical characteristics

(unless noted)

T_A = 0°C to +70°C

I_O = 200 mA (Note 2)

Part Number		LM342-05		LM342-06		LM342-08		LM342-10		LM342-12		LM342-15		LM342-18		LM342-24	
Input Voltage (unless otherwise noted)		10 V		11 V		14 V		16 V		19 V		23 V		27 V		33 V	
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Units
V _O Output Voltage	T _J = 25°C	4.8	5	5.2	5.75	6	6.25	7	7.7	8	8.3	9	9.6	10	10.4	11.5	V
	P _D = I _O = 1 - 200 mA V _{IN} =	4.75	5.25	5.7	6.3	6.3	6.4	9.5	10.5	11.4	12.6	14.25	15.75	17.1	18.9	22.8	25.2
ΔV _O Line Regulation	T _J = 25°C	(8 - 20)	100		(9 - 21)	120	160	(13.5 - 25)	(11.5 - 23)	(15.2 - 27)	240	(18.5 - 30)	(22 - 33)	(28 - 38)		480	mV
	V _{IN} = () V	(7.5 - 25)			(8.5 - 25)			(13 - 25)	(11 - 25)	(15 - 30)		(18 - 30)	(21 - 33)	(27.2 - 38)			
Load Regulation	T _J = 25°C	100			120	160		200		240		300		360		480	mV
	I _O = 1 - 200 mA																
Long Term Stability	T _J = 25°C	20			24	6		40		48		60		72		96	mV 1000 hrs
	I _O = 1 - 200 mA																
Quiescent Current	T _J = 25°C	6			6			6		6		6		6		6	mA
	I _O = 1 - 200 mA																
ΔI _O Quiescent Current Change	T _J = 25°C	0.5			0.5			0.5		0.5		0.5		0.5		0.5	
	V _{IN} = () V	1.5			1.5			1.5		1.5		1.5		1.5		1.5	
v _n Output Noise Voltage	T _J = 25°C (Note 3)	40			48			80		96		120		150		190	μV
	f = 10 Hz - 10 kHz																
ΔV _{IN} Ripple Rejection	f = 120 Hz	45	60	43	59	39	57	36	55	36	64	32	51	31	48	27	dB
	T _J = 25°C	2			2			2		2		2		2		2	V

Note 1: Thermal resistance of the Metal Can Package (H) without a heat sink is 40°C/W junction to case and 140°C/W junction to ambient. Thermal resistance of the TO-202 Package (P) without a heat sink is 12°C/W junction to case and 80°C/W junction to ambient.

Note 2: The electrical characteristics data represent pulse test conditions with junction temperatures as shown at the initiation of tests.

Note 3: Recommended load of 0.01 μF to limit high frequency noise bandwidth.

Voltage Regulators

LM145/LM245/LM345 negative three amp regulator

general description

The LM145 is a three-terminal negative regulator with a fixed output voltage of -5V or -5.2V , and up to 3A load current capability. This device needs only one external component—a compensation capacitor at the output, making it easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM145 immune to overload conditions. The regulator has current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shutdown prevents junction temperatures from exceeding safe limits during prolonged overloads.

Although primarily intended for fixed output voltage applications, the LM145 may be programmed for higher

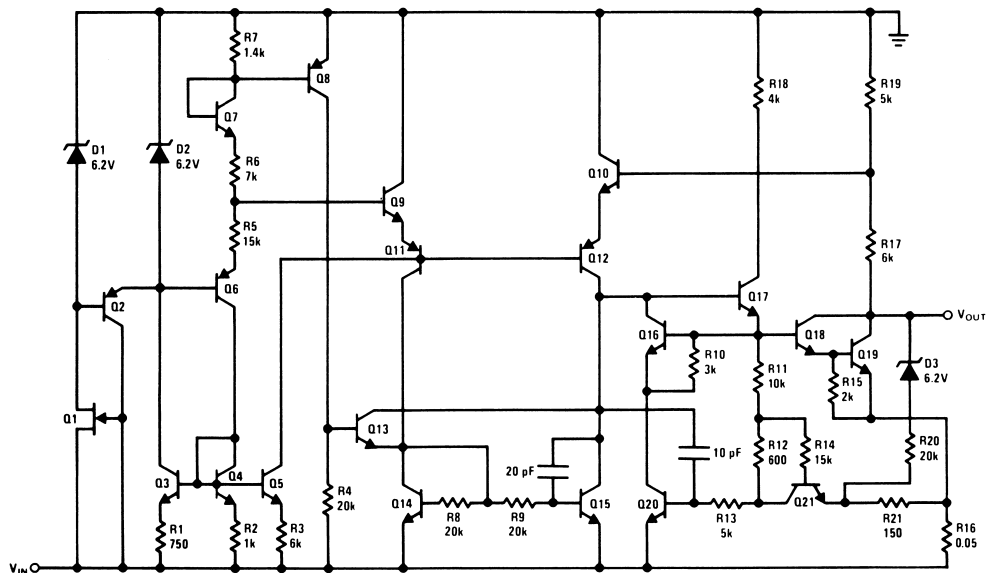
output voltages with a simple resistive divider. The low quiescent drain current of the device allows this technique to be used with good regulation.

The LM145 comes in a hermetic TO-3 package rated at 25W. Two reduced temperature range parts, LM245 and LM345, are also available.

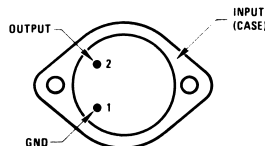
features

- Output voltage accurate to better than $\pm 2\%$
- Current limit constant with temperature
- Internal thermal shutdown protection
- Operates with input-output voltage differential of 2.8V at full rated load over full temperature range
- Regulation guaranteed with 25W power dissipation
- 3A output current guaranteed
- Only one external component needed

schematic and connection diagrams



TO-3 (K)



BOTTOM VIEW

Order Number LM145K, LM245K or LM345K
See Package 18

absolute maximum ratings

Input Voltage 20 V
Input-Output Differential 20 V
Power Dissipation Internally Limited

Operating Junction Temperature Range
LM145
LM245
LM345

-55°C to +150°C
-25°C to +125°C
0°C to +125°C
-65°C to +150°C
+300°C

electrical characteristics unless noted

$T_J = -55^\circ\text{C}$ to $+150^\circ\text{C}$ LM145
 -25°C to $+150^\circ\text{C}$ LM245
 0°C to $+125^\circ\text{C}$ LM345

Storage Temperature Range
Lead Temperature (Soldering, 10 seconds)

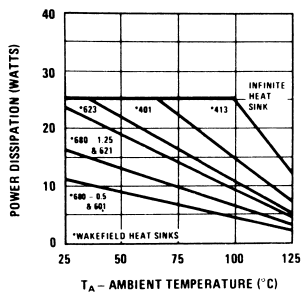
Part Number		LM145K-5.0 LM245K-5.0												LM345K-5.0												LM145K-5.2 LM245K-5.2												LM345K-5.2												Units
Input Voltage (unless otherwise noted)		7.5 V												7.5 V												7.5 V												7.5 V												
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max																						
V _O	Output Voltage	-4.9	-5	-5.1	-4.8	-5	-5.2	-5.1	-5.2	-5.3	-5	-5.2	-5.4	-5	-5.2	-5.4	-5	-5.2	-5.4	-5	-5.2	-5.4	-5	-5.2	-5.4	-5	-5.2	-5.4	V																					
	P _D ≤ 25 W I _O = 5 - 3000 mA	-4.8		-5.2	-4.75		-5.25																					-5.45																						
	V _{IN} = - (7.8 - 20) V																																																	
ΔV _O	Line Regulation (Note 2)		5	15		5	25		5	25		5	15		5	15		5	15		5	15		5	15		5	25	mV																					
	V _{IN} = I _O = 5 mA																																																	
	- (7.5 - 20) V																																																	
Load Regulation (Note 2)	T _J = 25°C		30	75		30	100		30	100		30	75		30	75		30	75		30	75		30	75		30	100																						
	I _O = 5 - 3000 mA																																																	
I _Q	Long Term Stability		5	50		5	50		5	50		5	50		5	50		5	50		5	50		5	50		5	50	mV 1000 hrs																					
	Quiescent Current		1	3		1	3		1	3		1	3		1	3		1	3		1	3		1	3		1	3																						
v _n	Output Noise Voltage f = 10 Hz - 100 kHz		150				150									150													μV																					
	C _{LOAD} = 4.7 μF																																																	
	T _J = 25°C																																																	
I _{SC}	Short Circuit Current		4				4		4	5		4			4														A																					
	V _{IN} = -7.5 V																																																	
	V _{IN} = -20 V		2				2	3.5		2	3.5		2			2																																		
θ _{JC}	Thermal Resistance, Junction-to-Case		2				2		2			2			2														°C/W																					

Note 1: Although power dissipation is internally limited, electrical specifications apply only for power levels up to 25 W. For calculations of junction temperature rise due to power dissipation, use a thermal resistance of 35 $^\circ\text{C/W}$ for the TO-3 with no heat sink. With a heat sink, use 2 $^\circ\text{C/W}$ for junction to case thermal resistance.

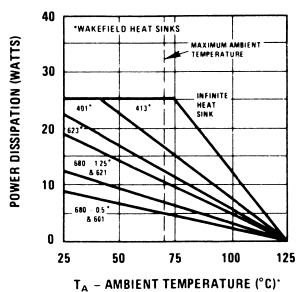
Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, pulse testing with a low duty cycle is used.

typical performance characteristics

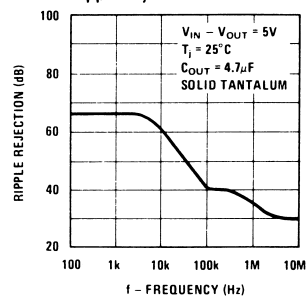
Maximum Average Power
Dissipation for LM145,
LM245



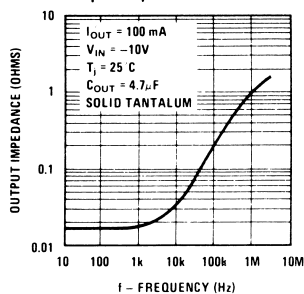
Maximum Average Power
Dissipation for LM345



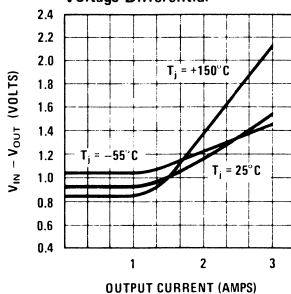
Ripple Rejection



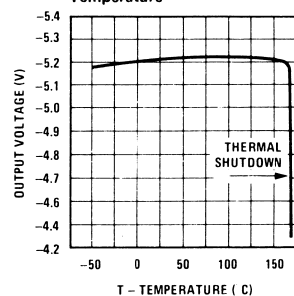
Output Impedance



Minimum Input-Output
Voltage Differential



Output Voltage vs
Temperature





LM78XX series voltage regulators

general description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expended to make the LM78XX series of regulators easy to use and minimize the number

of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

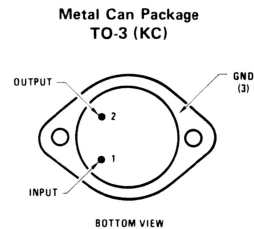
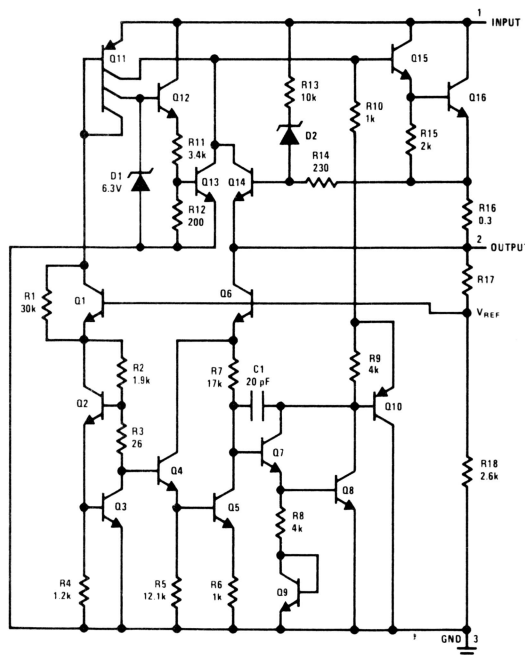
features

- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

voltage range

LM7805	5V	LM7815	15V
LM7806	6V	LM7818	18V
LM7808	8V	LM7824	24V
LM7812	12V		

schematic and connection diagrams



electrical characteristics (unless noted)

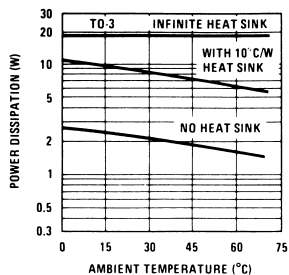
T_A = 0°C to +70°C

I_O = 500 mA

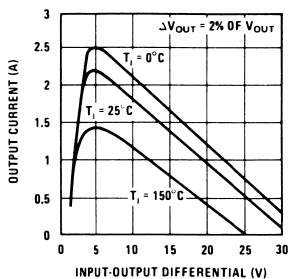
Part Number		LM7805		LM7806		LM7808		LM7812		LM7815		LM7818		LM7824		Units							
Input Voltage (unless otherwise noted)		10 V		11 V		14 V		19 V		23 V		27 V		33 V									
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max							
V _O	Output Voltage	4.8	5	5.2	5.75	6	6.25	7.7	8	8.3	11.5	12	12.5	14.4	15	15.6	17.3	18	18.7	23	24	25	V
	P _D = 15 W	4.75		5.25	5.7	6.3	7.6	8.4	11.4	12.6	14.25	15.75	17.1	18.9	22.8	25.2							
	I _O = 5 – 1000 mA																						
V _{IN} = () V		(7 - 20)		(8 - 21)		(10.5 - 23)		(14.5 - 27)		(17.5 - 30)		(21 - 33)		(27 - 38)									
ΔV _O	Line Regulation			50			60			80			120			150			180			240	mV
	T _J = 25°C																						
	V _{IN} = () V																						
	Load Regulation	I _O = 500 mA					100			160			240			300			360			480	
				(7 - 25)			(8 - 25)			(10.5 - 25)			(14.5 - 30)			(17.5 - 30)			(21 - 33)			(21 - 33)	
							100			120			160			240			300			360	
Long Term Stability	T _J = 25°C	I _O = 5 - 1500 mA																					
I _O	Quiescent Current	7	10		7	10		7	10		7	10		7	10		7	10		7	10		mV 1000 hrs mA
ΔI _Q	T _J = 25°C	I _O = () mA					0.5			0.5			0.5			0.5			0.5			0.5	
				(5 - 1500)			(5 - 1500)			(5 - 1500)			(5 - 1500)			(5 - 1500)			(5 - 1000)			(5 - 1000)	
v _n	Output Noise Voltage	40		45		52		55		60		75		90		110		170					μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 10 Hz – 100 kHz																					
				60		57		55		52		50		48		44							dB
		f = 120 Hz																					
Min	Dropout Voltage	2		2		2		2		2		2		2		2		2		2			V
V _{IN} - V _{OUT}																							

typical performance characteristics

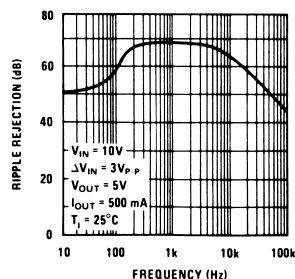
Maximum Average Power Dissipation



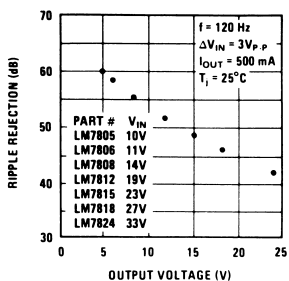
Peak Output Current



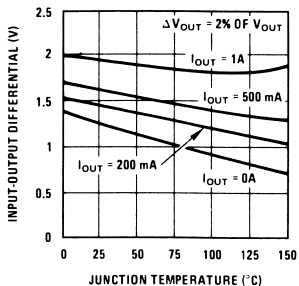
Ripple Rejection



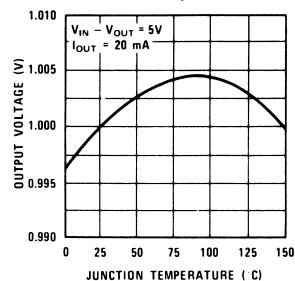
Ripple Rejection



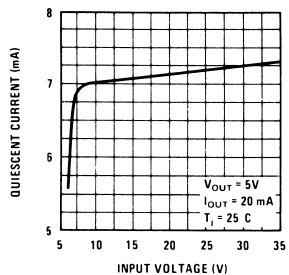
Dropout Voltage



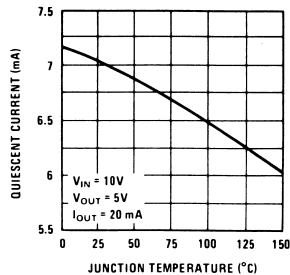
Output Voltage (Normalized to 1V at 25°C T_j)



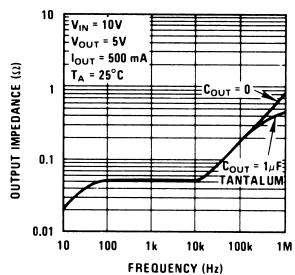
Quiescent Current



Quiescent Current



Output Impedance





Voltage Regulators

LM78LXX series three terminal positive regulators

general description

The LM78LXX series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. When used as a zener diode/resistor combination replacement, the LM78LXX usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM78LXX to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78LXX is available in the metal three lead TO-5 (H) and the plastic TO-92 (Z). With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes

too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

features

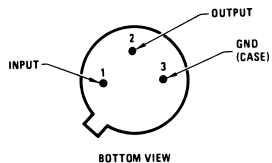
- Output voltage tolerances of $\pm 5\%$ (LM78LXXAC) and $\pm 10\%$ (LM78LXXC) over the temperature range
- Output current of 100 mA
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-92 and metal TO-39 low profile packages

voltage range

LM78L05	5V	LM78L15	15V
LM78L08	8V	LM78L18	18V
LM78L12	12V	LM78L24	24V

connection diagrams

TO-5 (H)

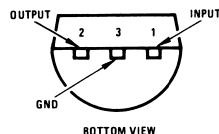


Order Numbers:

LM78L05ACH	LM78L05CH
LM78L08ACH	LM78L08CH
LM78L12ACH	LM78L12CH
LM78L15ACH	LM78L15CH
LM78L18ACH	LM78L18CH
LM78L24ACH	LM78L24CH

See Package 9

TO-92 (Z)



Order Numbers:

LM78L05ACZ	LM78L05CZ
LM78L08ACZ	LM78L08CZ
LM78L12ACZ	LM78L12CZ
LM78L15ACZ	LM78L15CZ
LM78L18ACZ	LM78L18CZ
LM78L24ACZ	LM78L24CZ

See Package 38

absolute maximum ratings

Input Voltage

(V_O = 5 V to 8 V)

(V_O = 12 V to 18 V)

(V_O = 24 V)

Internal Power Dissipation (Note 1)

Operating Temperature Range

Maximum Junction Temperature

Storage Temperature Range

Metal Can (H package)

Molded TO-92

Lead Temperature (Soldering, 10 seconds)

-65°C to +150°C

-55°C to +150°C

+300°C

electrical characteristics

(unless noted)

T_J = 0°C to +125°C

I_O = 40 mA

C_{IN} = 0.33 µF, C_O = 0.1 µF

Part Number		LM78L05C		LM78L08C		LM78L12C		LM78L15C		LM78L18C		LM78L24C		Units				
Input Voltage (unless otherwise noted)		10 V		14 V		19 V		23 V		27 V		33 V						
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max					
V _O Output Voltage	T _J = 25°C	4.6	5	5.4	7.36	8	8.64	11.1	12	12.9	13.8	15	16.2	18	19.4	22.1	24	25.9
	I _O = 1 - 70 mA or	4.5		5.5	7.2	8.8	10.8	13.2	13.5	16.5	16.2	19.8	21.4	26.4				
	I _O = 1 - 40 mA and V _{IN} = () V	(7 - 20)			(10.5 - 23)		(14.5 - 27)		(17.5 - 30)		(21.4 - 33)		(28 - 38)					
ΔV _O Line Regulation	T _J = 25°C	10	150		12	150		20	200		25	250		27	275		30	300
	V _{IN} = () V	(8 - 20)			(11 - 23)		(16 - 27)		(20 - 30)		(22 - 33)		(28 - 38)					
		18	200		20	200		30	300		30	300		32	325		35	350
Load Regulation	T _J = 25°C	7 - 20			10.5 - 23		14.5 - 27		17.5 - 30		21.4 - 33		27.5 - 38					
	I _O = 1 - 40 mA	5	30		6	40		10	50		12	75		15	85		20	100
	I _O = 1 - 100 mA	11	60		15	80		20	100		25	150		30	170		40	200
Long Term Stability	T _J = 25°C	12			20			24			30			45			56	
	T _J = 125°C	3	6		3	6		3	6.5		3.1	6.5		3.1	6.5		3.1	6.5
	T _J = 25°C		5.5			5.5			6			6			6			6
ΔI _O Quiescent Current Change	T _J = 25°C		0.2			0.2			0.2			0.2			0.2			0.2
	I _O = 1 - 40 mA																	
	V _{IN} = () V		1.5			1.5			1.5			1.5			1.5			1.5
v _n Output Noise Voltage	T _J = 25°C (Note 3)	(8 - 20)			(11 - 23)		(16 - 27)		(20 - 30)		(22 - 33)		(28 - 38)					
	f = 10 Hz - 10 kHz	40			60			80			90			150			200	
	f = 120 Hz	40	60		36	55		36	52		33	49		32	46		30	43
ΔV _{IN} Ripple Rejection ΔV _{OUT}	V _{IN} = () V	(8 - 18)			(12 - 23)		(15 - 25)		(18.5 - 28.5)		(23 - 33)		(29 - 35)					
	T _J = 25°C	1.7			1.7			1.7			1.7			1.7			1.7	
Min	Dropout Voltage																	
	V _{IN} - V _{OUT}																	

Note 1: Thermal resistance of the Metal Can Package (H) without a heat sink is 40°C/W junction to case and 140°C/W junction to ambient. Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4 inch leads from a PC board and 160°C/W junction to ambient with 0.125 inch lead length to a PC board.

Note 2: The maximum steady state usable output current and input voltage are very dependent on the heat sinking and/or lead length of the package. The data above represent pulse test conditions with junction temperatures as indicated at the initiation of tests.

Note 3: Recommended minimum load capacitance of 0.01 µF to limit high frequency noise bandwidth.

electrical characteristics absolute maximum ratings

(unless noted)

$T_J = 0^{\circ}\text{C}$ to $+125^{\circ}\text{C}$

$I_O = 40\text{ mA}$

$C_{IN} = 0.33\text{ }\mu\text{F}$, $C_O = 0.1\text{ }\mu\text{F}$

Input Voltage

($V_O = 5\text{ V}$ to 8 V)

($V_O = 12\text{ V}$ to 18 V)

($V_O = 24\text{ V}$)

Internal Power Dissipation (Note 1)

Operating Temperature Range

Maximum Junction Temperature

Storage Temperature Range

Metal Can (H package)

Molded TO-92

Lead Temperature (Soldering, 10 seconds)

-65°C to $+150^{\circ}\text{C}$

-55°C to $+150^{\circ}\text{C}$

$+300^{\circ}\text{C}$

Part Number		Input Voltage (unless otherwise noted)												Units					
Parameter	Test Conditions	LM78L05AC			LM78L08AC			LM78L12AC			LM78L15AC			LM78L18AC			LM78L24AC		
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
V _O Output Voltage	T _J = 25°C	4.8	5	5.2	7.7	8	8.3	11.5	12	12.5	14.4	15	15.6	17.3	18	18.7	23	24	25
	I _O = 1 – 70 mA or	4.75		5.25	7.6		8.4	11.4		12.6	14.25		15.75	17.2		18.9	22.8	25.2	
	I _O = 1 – 40 mA and V _{IN} = () V			(7 – 20)	(10.5 – 23)			(14.5 – 27)			(17.5 – 30)			(20.7 – 33)			(27 – 38)		
ΔV _O Line Regulation	T _J = 25°C	10	100		12	125		20	200		25	250		35	275		50	300	
	V _{IN} = () V	(8 – 20)			(11 – 23)			(16 – 27)			(20 – 30)			(21 – 33)			(28 – 38)		
		18	150		20	175		30	250		37	300		45	325		60	350	
		7 – 20			10.5 – 23			14.5 – 27			17.5 – 30			20.7 – 33			27 – 38		
Load Regulation	T _J = 25°C	5	30		8	40		10	50		12	75		15	85		20	100	
	I _O = 1 – 100 mA	11	60		15	80		20	100		25	150		30	170		40	200	
Long Term Stability		12			20			24			30			45			56		
I _Q Quiescent Current	T _J = 25°C	3	6		3	6		3	6.5		3.1	6.5		3.1	6.5		3.1	6.5	
	T _J = 125°C		5.5			5.5			6		6			6		6		6	
ΔI _Q Quiescent Current Change	T _J = 25°C		0.1			0.1		0.1			0.1			0.1			0.1		
	I _O = 1 – 40 mA																		
	V _{IN} = () V		1.5			1.5			1.5			1.5			1.5			1.5	
V _n Output Noise Voltage	T _J = 25°C (Note 3)	40			60			80			90			150			200		
	f = 10 Hz – 10 kHz																		
ΔV _{IN} Ripple Rejection	f = 125 Hz	41	62		37	57		37	54		34	51		33	48		31	45	
	V _{IN} = () V																		
Min V _{IN} – V _{OUT} Dropout Voltage	T _J = 25°C	1.7			1.7			1.7			1.7			1.7			1.7		

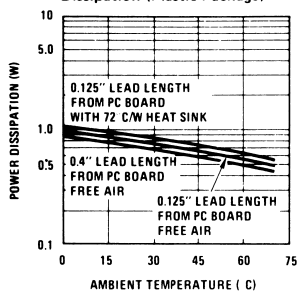
Note 1: Thermal resistance of the Metal Can Package (H) without a heat sink is 40°C/W junction to case and 140°C/W junction to ambient. Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4 inch leads from a PC board and 160°C/W junction to ambient with 0.125 inch lead length to a PC board.

Note 2: The maximum steady state usable output current and input voltage are very dependent on the heat sinking and/or lead length of the package. The data above represent pulse test conditions with junction temperatures as indicated at the initiation of tests.

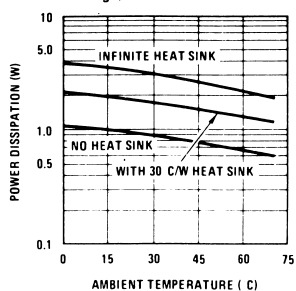
Note 3: Recommended minimum load capacitance of $0.01\text{ }\mu\text{F}$ to limit high frequency noise bandwidth.

typical performance characteristics

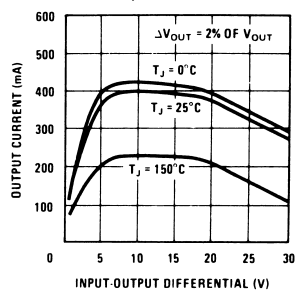
Maximum Average Power Dissipation (Plastic Package)



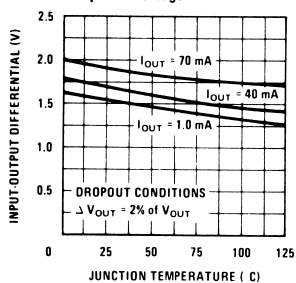
Maximum Average Power Dissipation (Metal Can Package)



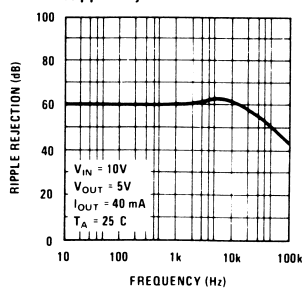
Peak Output Current



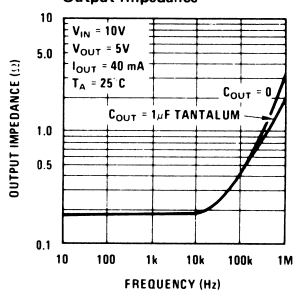
Dropout Voltage



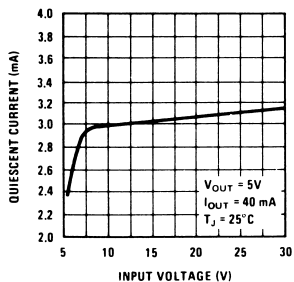
Ripple Rejection



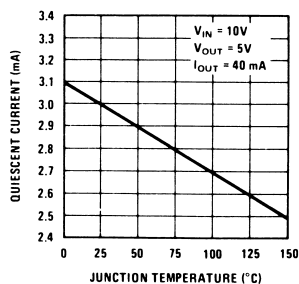
Output Impedance



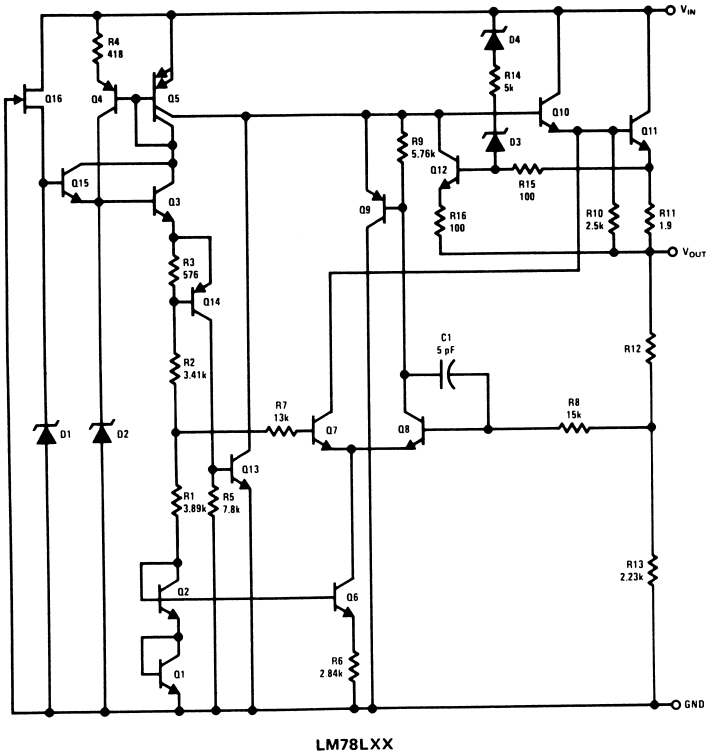
Quiescent Current



Quiescent Current



equivalent circuit





LM3910/LM340L* series three terminal positive regulators

general description

The LM3910 series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. The LM3910 is an improved version of the LM78LXX series with a tighter output voltage tolerance, higher ripple rejection, better regulation and lower quiescent current. The LM3910 regulators have $\pm 2\%$ V_{OUT} specification, $.04\%/V$ line regulation, and $.4\%$ load regulation. When used as a zener diode/resistor combination replacement, the LM3910 usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM3910 to be used in logic systems, instrumentation, Hi-Fi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

The LM3910 is available in the low profile metal three lead TO-39 (H) and the plastic TO-92 (Z). With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power

dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

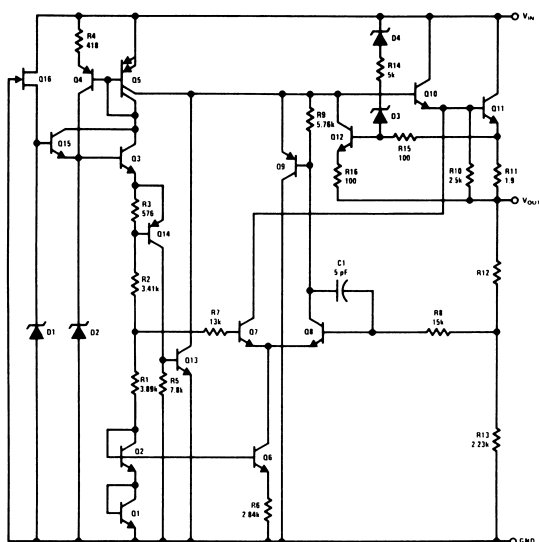
features

- Line regulation of $.04\%/V$
- Output voltage tolerances of $\pm 2\%$ at $T_J = 25^\circ C$ and $\pm 3\%$ over the temperature range
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-92 and metal TO-39 low profile packages
- Load regulation of $.4\%$ at 1 mA to 40 mA

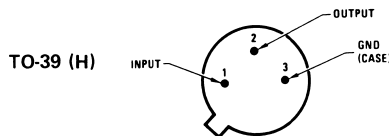
voltage range

LM3910-5.0	5 V	LM3910-12	12 V
LM3910-6.0	6 V	LM3910-15	15 V
LM3910-8.0	8 V	LM3910-18	18 V
LM3910-10	10 V	LM3910-24	24 V

equivalent circuit



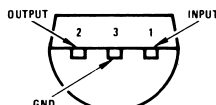
connection diagrams



BOTTOM VIEW
TO-5 Metal Can Package (H)
Order Numbers:

LM340LH-5.0	LM340LH-12
LM340LH-6.0	LM340LH-15
LM340LH-8.0	LM340LH-18
LM340LH-10	LM340LH-24

TO-92 (Z)



BOTTOM VIEW
TO-92 Plastic Power Package (Z)
Order Numbers:

LM340LZ-5.0	LM340LZ-12
LM340LZ-6.0	LM340LZ-15
LM340LZ-8.0	LM340LZ-18
LM340LZ-10	LM340LZ-24

*Note: LM340L is the new designation for the LM3910.

electrical characteristics

(Note 2) unless noted

$$T_A = 0^\circ\text{C to } +70^\circ\text{C}$$

$$I_O = 40\text{ mA}$$

$$C_{IN} = 0.33\text{ }\mu\text{F}, C_O = 0.01\text{ }\mu\text{F}$$

absolute maximum ratings

Input Voltage

$$(V_O = 5\text{ V to } 18\text{ V})$$

$$(V_O = 24\text{ V})$$

Internal Power Dissipation (Note 1)

Operating Temperature Range

Maximum Junction Temperature

Storage Temperature Range

Metal Can (H package)

Molded TO-92

Lead Temperature (Soldering, 10 seconds)

Internally Limited

$0^\circ\text{C to } +70^\circ\text{C}$

$+150^\circ\text{C}$

$-65^\circ\text{C to } +150^\circ\text{C}$
 $-55^\circ\text{C to } +150^\circ\text{C}$
 $+300^\circ\text{C}$

Part Number		LM3910-5.0		LM3910-6.0		LM3910-8.0		LM3910-10		LM3910-12		LM3910-15		LM3910-18		LM3910-24			
Input Voltage (unless otherwise noted)		10 V		11 V		14 V		16 V		19 V		23 V		27 V		33 V			
Parameter	Test Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max
V _O	Output Voltage	4.9	5	5.1	5.88	6	6.12	7.84	8	8.16	9.8	10	10.2	11.75	12	12.25	14.7	15	15.3
	I _O = 1 – 70 mA or (Note 4)	4.85		5.15	5.82		6.18	7.76		8.24	9.7		10.3	11.65		12.35	14.55	15.45	17.46
	I _O = 1 – 40 mA and V _{IN} = () V	(7 – 20)		(8.2 – 21)		(10.2 – 23)		(12.2 – 25)		(14.3 – 27)		(17.5 – 30)		(20.5 – 33)		(26.7 – 38)			
ΔV _O	Line Regulation	18	30	20	35	20	42	25	55	30	65	37	70	45	80	60	100		
	T _J = 25°C	(7 – 25)		(8 – 25)		(10.2 – 25)		(12.2 – 30)		(14.2 – 30)		(17.3 – 30)		(20.4 – 33)		(26.5 – 38)			
	V _{IN} = () V																		
Load Regulation	T _J = 25°C	5	20	6	25	8	30	10	35	10	40	12	50	15	65	20	80		
	I _O = 1 – 40 mA																		
	I _O = 1 – 100 mA	11	40	13	50	15	60	20	70	20	80	25	100	30	130	40	160		
Long Term Stability	T _J = 25°C	12		14		20		24		24		30		45		56			
	T _J = 125°C	3	4.5	3	4.5	3	4.5	3	4.5	3	4.5	3	4.5	3	4.5	3	4.5	3	4.5
	I _O = 1 – 40 mA																		
ΔI _Q	Quiescent Current	0.1		0.1		0.1		0.1		0.1		0.1		0.1		0.1			
	T _J = 25°C																		
	Change																		
v _n	Output Noise Voltage	40		50		60		70		80		90		150		200			
	f = 10 Hz – 10 kHz																		
	f = 120 Hz	55	62	53	60	51	58	50	57	47	54	45	52	44	50	41	46		
ΔV _{IN} ΔV _{OUT}	Ripple Rejection	1.7		1.7		1.7		1.7		1.7		1.7		1.7		1.7			
Min V _{IN} – V _{OUT}	Dropout Voltage	1.7		1.7		1.7		1.7		1.7		1.7		1.7		1.7			
	T _J = 25°C																		
	ΔV _O = 1% of V _O																		

Note 1: Thermal resistance of the Metal Can Package (H) without a heat sink is 40°C/W junction to case and 140°C/W junction to ambient. Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4 inch lead from a PC board and 160°C/W junction to ambient with 0.125 inch lead length to a PC board.

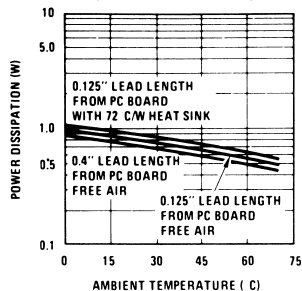
Note 2: The maximum steady state usable output current and input voltage are very dependent on the heat sinking and/or lead length of the package. The data above represent pulse test conditions with junction temperatures as indicated at the initiation of current.

Note 3: It is recommended that a minimum load capacitor of $0.01\text{ }\mu\text{F}$ be used to limit the high frequency noise bandwidth.

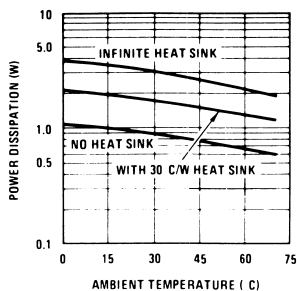
Note 4: The temperature coefficient of V_{OUT} is typically within $\pm 0.01\%$ $V_O/^\circ\text{C}$.

typical performance characteristics

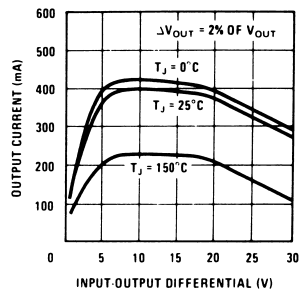
Maximum Average Power Dissipation (Plastic Package)



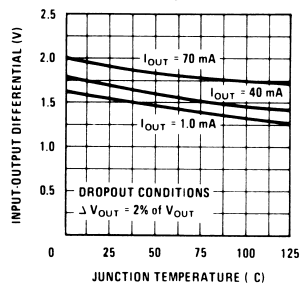
Maximum Average Power Dissipation (Metal Can Package)



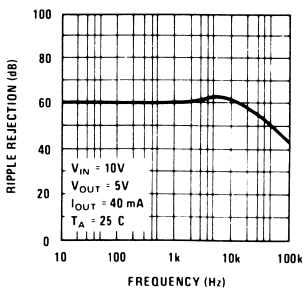
Peak Output Current



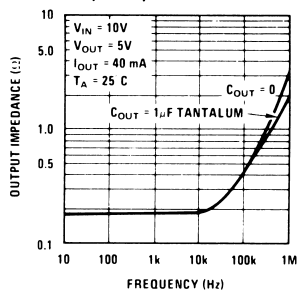
Dropout Voltage



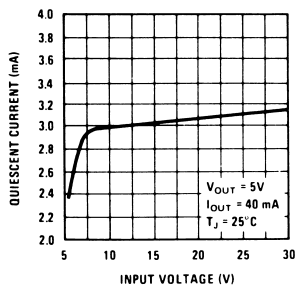
Ripple Rejection



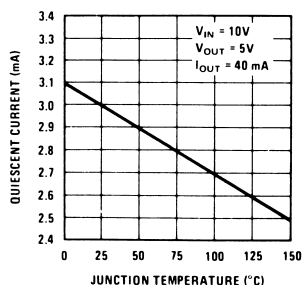
Output Impedance



Quiescent Current



Quiescent Current



NOTES

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NOTES

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